THE EFFECT OF SOIL PHYSICO-CHEMICAL PROPERTIES, LIME, GYPSUM AND FERTILIZER MATERIALS ON YIELD AND QUALITY OF PEANUTS (*Arachis hypogaea* L.)

By

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To my grandparents, Mbata and
Mathemba, and to my mother and father

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Major Department: Soil Science

Laboratory, greenhouse, and field experiments were conducted to determine soil physico-chemical properties of 10 soils of Malawi. Effects of these soils on the calcium supplying capacity of lime and gypsum were studied including the effect of lime on solubility and movement of gypsum. The effect of lime, gypsum, and other fertilizer materials were evaluated from the yield and quality of peanuts (*Arachis hypogaea* L.). Soil texture, type of soil colloid, cation exchange capacity, and organic matter content were the most important factors in determining the availability and retention of Ca and other cations in the soil. Lime supplied much less soluble Ca and had no effect on the dissolution of gypsum. Lime significantly reduced both the movement of surface-applied gypsum and loss of cations from the soil because of the increased cation exchange capacity. Greenhouse experiments showed an increase in yield of tops of peanuts with increasing rates of lime and Mn. However, field experiments showed no significant peanut yield response of tops and pods and quality characteristics to supplemental application of gypsum, Mn, K, N or inoculum over that obtained by liming Lakeland and Arredondo fine sands to exchangeable Ca levels over 400 ppm. Only dolomite [$CaMg(CO_3)_2$] significantly increased yield of unshelled kernels (pods) of Florunner peanuts.

Chairman

INTRODUCTION

The peanut (Arachis hypogaea L.) is an important food and economic crop. It is second only to corn as an important food crop in Malawi. Peanut yields have almost doubled during the last 10-year period in the United States due to better varieties, better disease and weed control, better cultural practices, and greater use of lime coupled with a more balanced soil fertility program.

While peanut production is on the rise in Malawi, the yields are much lower than those in the United States. Research in peanut mineral nutrition during the past 30 years has shed some light on the problems of peanut production. Calcium (Ca) is one nutrient that has been deemed indispensable for the production of maximum yield and quality of peanuts. Lime and gypsum are the two main sources of Ca for peanuts; the former serves the dual role of supplying Ca and raising the pH, while the latter supplies both Ca and S. In spite of the progress made in peanut nutrition, there are still reports of poor pod filling and infrequent peanut presponses to lime, gypsum and fertilizer application in some areas of the world. These problems seem to be associated with both insufficient use of lime and gypsum to correct soil acidity and probable Ca deficiency, and certain other soil physico-chemical properties that are important in determining soil fertility.

The traditional practice of incorporating lime into the soil before planting and top-dressing with gypsum in the fruiting zone when the plants are in bloom is to ensure adequate available Ca during the critical period of fruit development. The majority of peanuts are grown on sandy soils, which are usually acid. Lime, if given enough time to react, will not only raise the pH to an optimum level, and supply adequate Ca for the developing fruit, but also improves the cation exchange capacity of the soil. The latter favors the retention and thereby reduces leaching of cations. Further, the prior application of lime probably tends to reduce the solubility of gypsum due to the common ion effect. In spite of its low solubility, if given enough time to react, lime could provide adequate calcium, hence making gypsum top-dressing unnecessary. The movement of surface-applied Ca away from the fruiting zone, especially in sandy soils, could be another reason for the infrequent peanut response to lime and gypsum application in Malawi.

The objectives of this study were 1) to determine the physico-chemical properties of the soils of Malawi involved in the production of peanuts; 2) to determine the effect of lime on the solubility of gypsum and the subsequent movement of the resultant Ca; and 3) to study the effects of lime, gypsum Mn, K, N and inoculum application on the yield and quality of peanuts grown on Lakeland and Arredondo fine sands. These investigations were conducted in laboratory, greenhouse and field studies.

LITERATURE REVIEW

The Importance of Peanuts as a Food and Cash Crop

Today, peanuts (Arachis hypogaea, L.) are ranked thirteenth in importance to man as a food source (56). Although known to man as a food crop for many centuries, peanuts acquired economic importance only 125 years ago and even as late as 50 years ago in the third world countries of Africa, Asia and Latin America. Presently because of an increased awareness of the protein shortage existing in the world, the use of peanuts as a food and cash crop has increased substantially. Much of this increase is attributed to its high content of digestable protein (25-34%) and oil (44-56%) as well as its supply of aminoacids, including cystine and the vitamins, thiamin, riboflavin and niacin (56,76).

In 1972, the State of Florida had an average yield of 2,900 kg/ha on a total of 22,000 hectares, while Malawi, however, averaged a mere 600 kg/ha on a total of 404,000 hectares (56); with yields being very variable throughout that country. A main reason for the doubling of peanut yields in the U.S.A. during the past ten years can be attributed to the improvement of soil fertility and better use of fertilizers based on soil and plant analyses. It is the policy and hope of the Malawi government to increase and encourage the production of good quality peanuts. Factors recognized are the use of better varieties, better disease and weed control methods, better cultural practices, including improved harvesting practices, and, above all, proper use of lime and fertilizers to ensure a more balanced soil fertility program. It is only through such an effort that the country can meet increasing domestic and foreign demands for its peanuts.

Physiological Role of Calcium in Plants

Nutrient culture experiments of Harris (43) Bledsoe et al. (12,13) Mizuno (62,63) and Bolhius and Stubbs (15), all indicated that seedling growth was retarded in nutrient solutions very low or lacking in calcium (Ca). Those findings are applicable to many other plants. For many years it was not realized that even brief exposure of plant tissue to solutions lacking Ca can cause injury (39). The fact is that Ca plays an important role in cell division and extension, in membrane structure and function, in the plant uptake of other ions, and in Rhizobia root infection (26,38,40).

The process of cell division has a small but specific requirement for Ca associated with differentiation of organelles in the cytoplasm (38,40). The beneficial effects of Ca on the integrity of plant membrane structures such as the nuclear envelope, plasmalemma, mitochondria and Golgi structure has been recognized (40). Calcium increases potassium uptake, and reduces its leakage and that of other ions from roots (38).

Legumes have been reported to have a high Ca requirement. Nodulation of legumes is very poor at pH 5 or lower but even when the pH is 5.5 or higher, nodulation is sparse unless adequate Ca is present (28). Root infection or nodule initiation in legumes has a higher Ca requirement than either nodule development or growth of the host plant supplied with fixed N (40).

Calcium is of utmost importance for the growth and development of the gynophore into fruit and must be present in relative abundance in the soil immediately surrounding the gynophore (26). The significance of Ca in this regard has been elucidated by Bledsoe et al. (12), Bledsoe and Harris (13) and Mizuno (62,63,64,65,66).

Role of Calcium in Peanut Nutrition

Research in peanut nutrition during the last 30 years has resulted in a better understanding of (1) nutrient requirement of the peanut plant, (2) better understanding of the mechanism of Ca absorption by the peanut fruit and (3) the dependence of yield and quality on nutrient balance (19,20,26,32,42).

The peanut flowers above ground, and after the flower is fertilized, a "peg" is formed which, because of its geotropic nature, grows invariably downward, penetrating the soil and eventually developing into fruit (44,58,75). Consequently both the root and fruit develop in the soil and the area in which they develop are generally referred to as the rooting and fruiting zones, respectively (15,26,44,62,63,64,75).

Calcium must be readily available in the fruiting zone for maximum yield and quality of peanuts (9,15,17,18,19,26,44,62,65,76). The seed does not develop satisfactorily without Ca being in contact with the developing fruit, irrespective of how much Ca or other nutrients are in contact with the roots (15,17,44,75). This is because the Ca absorbed by the roots is not translocated to the developing fruit (12,26). Further, the concentration of a large number of pegs within a small volume of soil puts a strain on the Ca reserve in the fruiting zone (12, 75).

Calcium deficiency of peanuts is evidenced by unfilled pods (9,26), darkening of the plumule of the seed embryo, reduced pod development and in severe cases, chlorosis, petiole breakdown, wilting and death of terminal bud and root disorganization (75).

Burkhart and Collins (26) separated the fruiting zone from the rooting zone and were the first to demonstrate the need of Ca in the fruiting zone for good fruit development. Later Brady and Colwell (18), Brady et al. (19,20) and Bolhuis and Stubbs (15) also demonstrated the roles of Ca, K, and Mg in peanut pod filling, both in the field and using the root/fruit split culture method developed by Burkhart and Collins. They all found that Ca had a remedial effect and K and Mg had adverse effect upon pod filling when added to the fruiting medium. Through the use of ^{45}Ca, Bledsoe et al. (12), Bledsoe and Harris (13) showed that immediately after the peg enters the soil, Ca stops moving from the rest of the plant to the peg. Harris (45,47), Wiersum (96) and Mizuno (62,63) demonstrated that water movement was always from the developing fruit towards the tops of the plants. Inasmuch as transport in the xylem is from moist toward dry areas and because the xylem is the principal source of Ca transport in the plant, Ca movement is always from the pods toward the top (12,1343,44,96,63,64,65,96). Bolhuis and Stubbs (15), Harris (44) and Mizuno (62,63,65) in similar experiments established that Ca is an indepensable nutrient throughout the growth of the peanut plant. They found that the lack of Ca results in reduced production of foliage, flower, root, fruit and seed due to inadequate internal movement of Ca through the peg.

The combination of the above evidence leaves little doubt that the major nutritional problem encountered in peanut production is Ca deficiency. Evidence indicates that the Ca requirement is much higher for fruit development that for vegetative growth (12,13,15,44).

Sources of Calcium for Peanut Production

Lime [$CaCO_3$ and $CaMg(CO_3)_2$] and gypsum ($CaSO_4 \cdot 2H_2O$) are the main sources of Ca for peanut production, with the former traditionally incorporated into the soil before planting and the latter surface-applied in the pegging zone when plants start to bloom freely. The soil reaction and Ca content of the soil determines the need for one or both of these materials (70,80,81,82). Lime serves several purposes among them is raising soil pH, eliminating toxic effects of aluminum (Al), and supplying Ca. If properly used it could maintain a highly favorable pH and soil Ca level. Gypsum ($CaSO_4 \cdot 2H_2O$), often termed "land plaster," furnishes both Ca and sulfur (S), but unlike lime, has been found to lower the pH (16).

The use of lime and/or gypsum in peanut production is determined by their local availability or their use in the production of other crops sometimes alternating with peanuts. Brady and Colwell (18,19) in field experiments on soils with low cation exchange capacity (CEC) and exchangeable Ca contents ranging from 0.2 to 2.2 me/100g obtained results indicating that the ratio of the yield obtained on the control plots to the yield on the limed plots was more closely related to the exchangeable Ca than to the pH of the limed soils. Lime did not increase peanut yield if the soil contained in excess of 1.4 me/100g exchangeable Ca. Brams (21) reported increases in peanut yields from lime application in West Africa. He recommended an initial application of 4 to 5 ton/ha of $CaCO_3$ followed by an annual application equivalent to 500 kg/ha of CaO to offset Ca losses. On soils with pH of 4.4 and Al saturation around 83% of total exchangeable cations, Brams failed to obtain response in peanut yield with lime application. It can only be assumed that Ca as a nutrient was not limiting.

On ferralitic soils in Uganda, Foster (38) obtained peanut yield response to lime application except in soils with pH ranging from 5.0 to 5.9. Response to lime was restricted to those sites with a mean level of exchangeable Ca of less than 6 me/100g and no lime response was obtained on sites with exchangeable Ca exceeding 12 me/100g. In Malawi experiments evaluating application of lime before planting did not produce significant and consistent positive yield increases (22). Later, Lawrence (55) found that in acid soils of Malawi (pH 4.3 to 4.9 measured in $CaCl_2$) either gypsum or lime application produced significant increases in peanut yield and quality. He emphasized incorporating lime by hand to produce sufficient utilizable Ca.

Brady and Colwell (19,20) conducted experiments involving the application of sulfates of potassium (K), magnesium (Mg), and Ca to the fruiting and rooting zone. They found the yield of peanuts was doubled with application of calcium sulfate to the fruiting zone but yield was reduced with other treatments. This confirmed the higher Ca requirement for the fruiting of the peanut than for vegetative growth. In experiments conducted on soils with various Ca content at North Carolina Agricultural Experiment Station, very marked increases in yield were obtained from addition of gypsum to soil low in Ca. The gypsum additions resulted in higher shelling percentage (17,18,19). Once again, gypsum exerted a marked beneficial effect on yield and quality on soil low in Ca (0.45 me/100g). Lime, however, did not provide the Ca requirement of the fruit in low Ca soils. Gypsum placed in the fruiting zone was not only effective in increasing pod filling but also reduced plumule damage, and pod breakdown (42,43,48,83). Application of gypsum to soil that had received 600 to 1000 kg/ha dolomite before planting still increased yield. Lime application just before planting failed because time was too short for the lime to dissolve and furnish adequate Ca (55,58).

The primary consideration in the use of lime and gypsum is the need to furnish an adequate supply of Ca. Further, it seems that peanut growing in highly leached, poorly buffered soils of the humid tropics may respond more to small amounts of lime and gypsum than most crops because of the critical Ca requirement of peanuts.

Plant Factors Affecting Ca Availability

Many Ca deficiencies in plants are actually the result of poor Ca transport or translocation (38). Calcium immobility is more pronounced in older plant tissue because downward transport of Ca in many plants, more especially in peanuts, is inadequate to support fruit development in the Ca deficient soils (38,40).

There is evidence that the level of Ca essential for growth is very small and actually approaches that of a micronutrient (39). Critical levels, published for various plants, do not reflect a direct need for growth but rather the amount required to detoxify excesses of other cations in the plant, e.g. Cu, Fe, Mn, Zn, or Al. If other essential elements are in balance, the Ca requirements of plants are extremely low if toxic ions are also absent (36,38,40).

Soil Factors Affecting Ca Availability to Plants

Calcium Content of Soils

Soil Ca can be divided into three fractions: Ca in the soil solution, the exchangeable Ca and the non-exchangeable Ca. Generally in acid soils the major portion of Ca is found in the first two forms (7,38,59,72,76).

Various studies have shown that the concentration of Ca in the soil solution varies quite widely. It is affected by biological activity, the CO_2 content of the soil, the level of exchangeable Ca and type of soil exchange complex. Except in some acid soils having low CEC, Ca deficiency is not generally a primary growth limiting factor for growth of most plants (58,59,72).

Soil pH

The effect of the H^+ ion concentration on Ca availability, uptake and plant growth is difficult to determine because at low pH the quantities of Al, Mn, Zn, Cu, and Fe present may be toxic to plant growth. This is confirmed by reports that indicate better plant growth at pH 7.0 with low levels of Ca than with higher levels of Ca at pH 5.0 (7). Peanuts appear to give more direct yield response to Ca as a nutrient than to pH change (31,32,33,48,58). The yields were more closely related to the level of exchangeable Ca than to changes in soil pH.

Type of Soil Colloid and Percent Ca Saturation

The amounts of exchangeable Ca, the percent of Ca saturation, and the type of soil colloid determine the availability of Ca to plants. The Ca-saturation associated with good plant growth varies depending upon the type of soil colloid and plant species. Allaway (7) reported the availability of colloid-bound Ca to soybeans to decrease in the order: peat > kaolinite > illite > bentonite. Mehlich and Colwell (59) reported that Ca availability and peanut quality decreased in order: kaolinite > montmorillonite > organic colloid. Aluminum coated montmorillonite seems to have a higher preference for binding Ca over Mg. The levels of Ca saturation of soils at which plant growth is decreased was reported to vary from 4% to 40%. They concluded that, in acid mineral soils, the percentage of base saturation is more important than the total Ca present in determining the availability of Ca to plants.

Ratios Between Ca and Other Cations in Soil Solutions

Bennett and Adams (11) showed that the ratio of Ca to total-cations from 0.1 to 0.15 is required for optimum plant growth in acid soils and K is often antagonistic to Ca. In soil solution, K saturation greater than 10% has been known to reduce Ca uptake (36,39,40). In acid soils, Al-Ca antagonism is probably the most important factor affecting Ca uptake by plants (36,39,40).

Soil Factors Affecting Calcium Availability to Peanuts

Soils Ideal for Peanut Growth

Peanuts are unique in that both the root and fruit develope in the soil. Both the root and fruit are affected by the availability of Ca and other essential elements, as well as the supply of air and water.

According to Reid et al. (76), "a well drained, light-colored, loose, friable, sandy loam, well supplied with Ca and moderate amounts of organic matter" is ideal for peanuts. Peanuts grow well under favorable conditions of moderate rainfall (105-135 cm) during the growing season. Maximum yield and quality are obtained where such soils have a pH of 5.8-6.2 (9,22,58).

In the United States, peanuts are frequently grown on acid soils of very low CEC, containing inadequate Ca. These soils require heavy Ca application (76,80,81,82). In Malawi, peanuts are grown under a unimodal rainfall of 60-100 cm per year and on soils ranging from strongly ferralitic loamy sands with low fertility status to inherently fertile ferrogenous sandy clay loams and alluvial sandy loams (22,55). However, poor pod filling has been reported for several years despite lime and gypsum application (22,55). Inconsistencies in the results from Ca application trials may be attributable to other factors than Ca limiting yields. Certainly probably the optimum soil pH and exchangeable Ca are not the only requirements for an ideal peanut-soil environment.

Soils of the humid tropical regions differ widely in chemical, mineralogical and physical properties (52,53,98). If a large number of dissimilar soils exist within a small tropical region (25,52,53,98), then it would be unusual if inconsistencies did not occur among the above reported observations of peanut responses to Ca application. This is probably the case in Malawi.

Type of Soil Colloid

Allaway (7), Mehlich and Colwell (59), and Mehlich and Ried (60), demonstrated that peanut fruit quality, measured by the percent of cavities filled, was influenced by type of soil colloid, CEC and percent Ca saturation. At any given level of Ca, fruit quality was higher when the colloid was predominantly kaolinitic rather than montmorillonitic or organic. This was largely a result of the relative Ca bonding of the different exchange systems. Higher percent of Ca saturation was required before appreciable change in fruit quality was noticeable in montmorillonitic and organic colloids. The results obtained were explained on the basis of differences in bonding energy by which Ca was held by the three types of colloids. The cation exchange in kaolinite type colloid is largely extracellular, resulting from broken edges in the lattice, while in the montmorillonitic and organic type it is greater and largely intracellular (58,59,60). Swartzen-Allen and Matijevic (88) seem to agree that for clays which swell in the presence of water such as montmorillonite, the cations are held on the external surfaces of the aggregates and between the unit layers, whereas in non-swelling clays the cations are sorbed onto the external surfaces only. In aqueous suspensions, some of the cations may remain closely held in the Stern layers. The association of cations with montmorillonite and kaolinite increases as $Na^+ < K^+ < Mg^{2+} < Ca^{2+}$ and $Li^+ < Na^+ < K^+ < NH_4^+$, respectively (88).

The capacity of the soil to supply Ca for adequate peanut yield and quality depends mainly on the CEC, Ca saturation and kind of soil colloid in the soils. Calcium deficiency in soils does not depend upon the soil being acid as much as on the levels of Ca in relation to other cations so that Ca deficiency could be described in terms of the ratio of Ca to total cations in the soil solution.

Soil Physico-Chemical Properties Important in Plant Growth

Soil fertility studies, directly important in the food supply for both animals and humans, are based on the physico-chemical studies of the soil. A basic understanding of the factors involved in the availability of nutrients, is a prerequisite for the successful production of crops.

In the study concerning the availability of nutrients for plants important factors are transport of ions to plant roots, and the general phenomena of leaching, fixation, ion exchange, and solubility. The central feature is the relationship between the solid and liquid phases of the soil (1,2,5,16).

The Colloidal Fraction

The colloidal fraction of the soil phase is made up of large amounts of phyllosilicate clay minerals with smaller amounts of crystalline metallic oxides and hydroxides, non-crystalline inorganic gels, and organic matter. These components exist as discrete particles or may interact to form coatings of non-crystalline particles on the surfaces of crystalline components (49,92,98).

Phyllosilicates which dominate the colloidal fraction of most soils, are composed of small plate-like crystalline, layered minerals. They are divided into three main groups, viz. montmorillonite, illite and kaolinite (85,88,98). The first two are three-layer clays with a unit layer consisting of a sheet of octahedral alumina sandwiched between two sheets of tetrahedral silica. In kaolinite, the unit layer is composed of one sheet of silica and one sheet of alumina (85,87,88,98).

The metallic cyrstalline oxides and hydroxides, smaller in size and quantity than the phyllosilicates, have a larger surface area which renders them very reactive, forming coatings on the phyllosilicates, when present in large amounts (92). The prominent members of this group are quartz (SiO_2), geothite ($FeOOH_2$), hematite (Fe_2O_3) and gibbsite ($Al(OH)_3$).

Non-Crystalline Material

Non-crystalline materials are colloidal material either too small or too disorganized to be identifiable with X-ray diffraction and these are structurally and chemically difficult to identify or formulate (49, 92,98). Organic matter, a decomposition product of animal and plant residues, is a non-crystalline material made up of a disordered conglomerate of organic rings and chains with various carbonyl, phenol, carboxyl, hydroxyl, methoxy and amino functional groups (84).

Distribution

There is a distinct latitudinal distribution of soils dominated by the various systems, depending on the genetic factors that affected the soils development (25,92,98). There is a tendency for the colloidal fraction of temperate soils to be predominantly pure phyllosilicates while those of the tropics contain oxides and other non-crystalline in large enough amounts to mask the properties of the phyllosilicates (92,94,98).

Any combination of the above colloidal systems results in soils with distinct chemical properties which affect the soil management techniques required for successful crop production (52,53,92,98).

Sources of Colloidal Charges

Electrokinetic studies of clay minerals indicate that, at all pH values above two or three, clay minerals carry a net negative charge which originates from either isomorphic substitution and lattice imperfections or broken bonds at the edges of the particles, chiefly structural hydroxyls (52,53,92,98). In highly-charged clay minerals, as montmorillonite and vermiculite, isomorphic substitution is responsible for approximately 80 to 100 me/100g of observed CEC, while in kaolinite with low CEC crystal imperfections account for the charge of 1 to 5 me/100g (85,88,98).

Although the cation exchange properties of oxides and hydrous oxides are small, their large surface area and cementation properties determine to a large extent, the physical structure of soils (98).

The exchange capacity of organic matter is relatively high, 100 to 200 me/100g, and results from a formation of salts of cations with -COOH and -OH groups (84,85,92,97). The CEC of kaolinite and organic matter are very much pH dependent (84,92,97).

The above soil colloids can be divided into constant surface charge and constant surface potential types, with the former deriving their charge from ionic substitutions within the crystal lattice, typified by layer silicates and the latter with the surface charge determined by the nature of the potential determining ions adsorbed on the surface (52,53, 92,98). The constant surface charge results from isomorphic substitution of Al for Si in the tetrahedral, and Fe, Mg, Ni etc., for Al in an octahedral layer. In the second type of colloid, H^+ and OH^- are the potential determining ions. For minerals with permanent charge, such as montmorillonite, addition or removal of salt from the soil solution causes a proportionate change in potential, since the surface charge (CEC) is a fixed value (52,53,92). For minerals with constant potential, pH-dependent charges as in kaolinite and organic matter exhibit changes in surface charge with variations in salt concentration. If surface potential is held constant, the charge changes with pH.

The relationship between surface potential and pH is expressed by the Nernst equation:

$$\phi = \frac{RT}{F} \ln \frac{[H^+]}{[H^\circ]} \qquad [1]$$

where ϕ = potential in volts,

R = the gas constants,

T = absolute temperature,

F = Faraday's constant,

$[H^+]$ = hydrogen ion concentration of the system, and

$[H°]$ = hydrogen ion concentration when ϕ is zero.

When the [H] is expressed as pH and the R, T, and F terms, are, essentially constant, the above equation can be rewritten as:

$$\phi = 0.059\ (ZPC - pH) \qquad [2]$$

where the zero point of charge, ZPC, is the H^+ ion concentration when $\phi = 0$. This is a useful soil management parameter for soils with pH dependent charge minerals of low net charge such as oxides and hydroxides or non-crystalline materials (5,52,53,87). Generally, organic matter addition, or adsorbed P and Ca decrease the ZPC while SO_4^{2-} increases it (5,52,53,87,92). When the soil has pH = ZPC, charge and pH are independent of salt concentration. When the pH in N KCl is equal to pH in water, the field pH is equal to ZPC and the soil has low affinity for monovalent ions such as NH_4^+ or Cl^- (52,53,57,92).

Soil Acidity

In constant charge surfaces Al^{3+} ions and not H^+ ions are retained as counter-ions on the surfaces of phyllosilicate minerals in the soil. These are responsible for soil acidity because H^+ ions are rarely adsorbed in the double layer of natural soils unless the pH is below 4 (30,92). It is not only the Al^{3+} ion but also $Al(OH)^{2+}$ and $Al(OH)_2^+$ which can be exchanged and be introduced as counter-ions as a result of the hydrolysis of Al^{3+}:

$$Al^{3+}\cdot 6H_2O + H_2O \longrightarrow Al(OH)^{2+}\cdot 5H_2O + H_3O^+ \qquad [3]$$

$$Al(OH)^{2+}\cdot 5H_2O + H_2O \longrightarrow Al(OH)_2^+\cdot 4H_2O + H_3O \qquad [4]$$

$$Al(OH)_2^+ \cdot 4H_2O + H_2O \longrightarrow Al(OH)_3 \cdot 3H_2O + H_3O^+ \quad [5]$$

The hydrolysis in equation [3] represents neutralization of monomeric Al which is toxic to plants at pH 5.5 or lower (92).

The second type of acidity is associated with constant potential surfaces and originates from the dissociation of H^+ ions from structural OH^- which, in turn, results in the creation of pH-dependent charge (30,92).

The dissociation of H^+ or Al^{3+} ions from functional groups in the organic fraction of the soil, which is also pH dependent, is a third source of soil acidity. The functional groups of carbonyls, phenols, and alcoholic hydroxyls are implicated, with carboxyls being the main functional groups at very low pH values (30,94,92).

Liming

In tropical regions more than in temperate regions, the supplying of Ca and Mg as nutrients after acid soils are limed may be more important than alleviating the low pH and its attendant phytotoxicities (72). Consequently, it is not uncommon to observe large increases in crop yield with minimal lime application in the tropics. This has proved to be true for peanuts (72,81,83).

Calcium carbonate applied to acid soils reacts with the soil water and dissolved CO_2 according to the following reactions (92):

$$CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2 \quad [6]$$

$$Ca(HCO_3)_2 \longrightarrow Ca^{2+} + 2HCO_3^- \quad [7]$$

$$HCO_3^- + H_2O \longrightarrow H_2CO_3 + OH^- \quad [8]$$

$$Y(Al^{3+} + H^{+}) + 4OH^{-} \longrightarrow Y^{4-} + Al(OH)_3 + H_2O \qquad [9]$$

$$Y^{4-} + 2Ca^{2+} \longrightarrow Y(2Ca^{2+}) \qquad [10]$$

where Y is the soil exchange complex. It is actually the OH^- and not the Ca that reacts to neutralize the acidic components.

In soils dominated by constant charge colloids, liming to pH between 6 and 6.5 is generally beneficial for most crops grown except for alfafa and other temperate legumes that require higher pH, and potatoes. that require lower pH values to control potato scab. Increasing the pH by liming these soils results in the neutralization of acidity by neutralizing the Al^{3+} and increasing the Ca concentration in the double layer (30).

Soil dominated by constant-potential colloids, like Oxisols, are rarely limed above pH 5.5 because: (1) At this pH Al^{3+} has been hydrolyzed, (2) There are no true surface charges for cations of H^+ or Al^{3+} to satisfy, (3) Additional lime only causes more OH^- ions to be adsorbed creating additional surface charges. The latter are satisfied by the Ca^{2+} from lime, resulting in the adsorption of both Ca^{2+} and OH^- into the double layer without any increase in the electrolyte concentration, and (4) Phosphate, Zn, Cu, Mn and Fe become less available (50,57,92).

Wide differences, which have not been satisfactorily explained, occur in crop yield responses to increasing pH, even among related soils. Inconsistencies in the report of liming and Ca application trials of peanuts may be attributed to the fact that the measured soil properties currently used in rationalizing observed plant behavior (soil pH and exchange cations) do not adequately define the plant-soil environment (72). Many tropical legumes can make maximum growth in extremely acid soils, and some strains of Rhizobium are highly acid tolerant, provided soil Mn level is low. Manganese toxicity is one of the chief causes of poor nodulation of legumes in acid soils of the tropics (72).

Peanuts maybe highly tolerant of Al, but are especially sensitive to soil acidity because of the high Ca requirement. If exchangeable Al is used as the criterion for liming, as it should be instead of pH per se, low rates are adequate for an economical approach to efficient crop production (38,73,75).

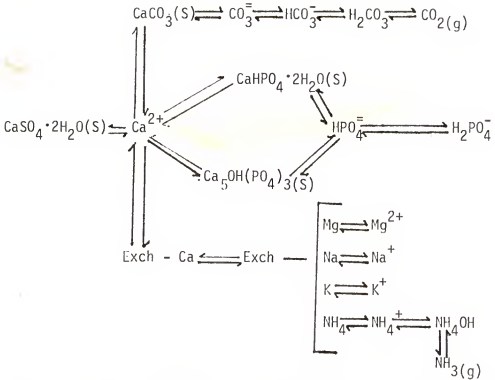
Dissolution and Movement of Gypsum and Lime in Soils

Soil Solution Calcium

The uptake of Ca by the roots and developing fruits of the peanut plant, like that of other plants, depends on the activity of Ca and other cations in the soil solution and the relation that exists between ions in solution and the exchangeable or solid-phase ions (10).

The sources of soil solution electrolytes are free soluble salts, adsorbed salts, solid phase compounds of slight solubility, and exchangeable cations (54). The solid phase is a heterogeneous mixture of compounds and minerals in equilibrium with their component ions. In the solid phase, equilibrium ions may be either exchangeable cations or the sparingly-soluble compounds of Ca and other cations. Adams (1,2) has shown that the role of the solid phase determines the plant's chemical environment only as it effects the composition of the soil solution.

The importance of the solid phase can be illustrated by taking for example, a soil treated with four sources of lime, viz.: $CaCO_3$, $CaSO_4 \cdot 2H_2O$, $CaHPO_4 \cdot 2H_2O$, and $Ca_5OH(PO_4)_3$ in which the Ca^{2+} equilibrium can be presented as follows:



[11]

where soil solution Ca^{2+} is in simultaneous equilibrium with solid phases of $CaCO_3$, $CaSO_4 \cdot 2H_2O$, $CaHPO_4 \cdot 2H_2O$, and $Ca_5OH(PO_4)_3$ and exchangeable Ca. All these equilibria are affected by the solution activities of the exchangeable cations and soil solution H^+, Mg^{2+}, Na^+, K^+, and NH_4^+. The soil solution concentration of Ca^{2+}, the common denominator of the various equilibria, is controlled by the solubility of $CaSO_4 \cdot 2H_2O$, $CaCO_3$, $CaHPO_4 \cdot 2H_2O$, and $Ca_5OH(PO_4)_3$ and cation exchange reactions between Ca^{2+} in solution and other adsorbed cations (1,2,54,91).

Solubility Product

The Ca supplying ability of $CaSO_4 \cdot 2H_2O$, $CaCO_3$, $CaHPO_4 \cdot 2H_2O$ and $Ca_5OH(PO_4)_3$ is determined by their respective dissolution-precipitation reactions, and the solubility product principle (1,2,11). The dissolution-precipitation reaction for gypsum can be presented as:

$$CaSO_4 \cdot 2H_2O \rightleftharpoons Ca^{2+} + SO_4^{2-} + 2H_2O \qquad [12]$$

and its activity solubility product (A_{sp}) is partly described by

$$A_{sp} = \frac{A_{Ca}\ A_{SO4}\ \cdot\ A^2_{H2O}}{A_{CaSO_4}\ \cdot\ 2H_2O} = M_{Ca}f_{Ca} \times M_{SO_4}\ f_{SO4} \qquad [13]$$

A is activity and M is the molar concentration (1,21,34,35,11,68,69,74,90). The activities of $CaSO_4 \cdot 2H_2O$ and H_2O are taken as unity. The activity, A, is the product of the molar concentration, M and the activity coefficient (f). The activity coefficient is computed from the Debye-Hückel equation which incorporates the ionic strength expression:

$$\log f = -\frac{0.509\ Z^2\ I^{1/2}}{1 + 0.33a\ I^{1/2}} \qquad [14]$$

where f = is the activity coefficient,

Z = charge of the species in solution,

I = is the ionic strength calculated $1/2\ \Sigma C_i Z_i^2$, where C_i is the actual molar concentration of each ion in solution and Z_i is its valence

a = ionic size in Å.

Ion-Pairs

In a saturated $CaSO_4 \cdot 2H_2O$ solution, the dissolved species include Ca^{2+}, SO_4^{2-} and $CaSO_4^{\circ}$, which is an ion-pair. Analytical measurements give the total Ca and SO_4 concentrations.

The extent to which free ions associate in solution is expressed by the traditional method for presenting the dissociation of weak electrolytes. For the ion-pair $CaSO_4^{\circ}$, the dissociation reaction is written as:

$$CaSO_4^{\circ} = Ca^{2+} + SO_4^{2-} \qquad [15]$$

and

$$K_D = \frac{A_{Ca} \cdot A_{SO4}}{A_{CaSO_4^\circ}} = \frac{M_{Ca} f_{Ca} \cdot M_{SO4} \cdot f_{SO4}}{M_{CaSO_4^\circ} \cdot f_{CaSO_4^\circ}} \qquad [16]$$

where K_D is the dissociation constant, A, M, and f are as above, and $f_{CaSO_4^\circ}$ is taken as unity (1,2,11,68,69). In solution, total Ca may be present as Ca^{2+}, $CaSO_4^\circ$, $CaHPO_4^\circ$, $Ca(H_2PO_4)^+$, and $CaHCO_3^+$ and the analytical procedure for determining solution Ca makes no distinction among the different species of Ca. Consequently, the active concentration of the Ca^{2+}, which is lower than the total above, must be calculated or determined by the Ca selective electrode (1,2,11,68,69). By combining equation [13] and [16] it is possible to determine the concentration of $CaSO_4^\circ$ (1,2,68,74,87).

The solubility product for gypsum accounting for $CaSO_4^\circ$ is 2.44 x 10^{-5} compared to that of 4.35 x 10^{-5} not accounting for the ion-pair (1,67,68,87).

Ionic Strength and Solubility

Gypsum solubility is increased in salts not having a common ion with those from gypsum. This is partially related to the activity solubility product A_{sp} where A_{sp} is the product of the activity of Ca^{2+} and SO_4^{2-}. Where ionic strength is increased by other soluble salts, the saturation solubility (S_{sp}) measured in moles per liter is related to the K_{sp} in pure water by the relationship:

$$\log S_{sp}/K_{sp} = A_{sp}(I^{1/2} - I_0^{1/2}) \qquad [17]$$

where K_{sp} is 4.35 x 10^{-5}, A_{sp} is that in equation [13], I_0 is the ionic strength in pure water, and I is the ionic strength with additional salts present. The increase in the Ca activity coefficient with the increase in inoic strength also means that active Ca and SO_4 concentrations must decrease (68). If either Ca^{2+} or SO_4^{2-} form complexes or ion-pairs with other anions or cations, then the solubility, but not the solubility product can increase (68,87).

The presence of $CaCO_3$ or $CaMg(CO_3)_2$ which can release common ion with $CaSO_4$ $2H_2O$ should reduce the solubility of gypsum due to the common ion effect (1,2,27). However if ion-pair formation is extensive, e.g., $MgCO_3^\circ$, $CaCO_3^\circ$, or $CaHCO_3^+$, then more gypsum can go into solution, and the Ca^{2+} concentration in solution is then determined by both $CaCO_3$ and $CaMg(CO_3)_2$ with K_{sp} values of 5×10^{-9} and 2.0×10^{-17}, respectively as compared to 4.35×10^{-5} for $CaSO_4$ $2H_2O$ (1,11,68,87).

Movement of Gypsum and Lime in Soils

Lime is incorporated into the soil before planting and gypsum is top-dressed when the peanuts are in bloom, to ensure an adequate supply of Ca during the period of fruit development (17,38,33,76).

The effectiveness of lime and gypsum as Ca suppliers depends, among other factors, on the rate of dissolution of both materials and the subsequent movement of the resultant Ca away from the fruiting zone. One of the major factors for lack of Ca response in peanuts could be associated with leaching of Ca beyond the fruiting zone.

The leaching of gypsum and lime have been studied extensively and according to Glas et al. (41) involve (a) bulk convective transport in the solution phase (b) hydrodynamic dispersion, and (c) chemical and physical reactions involving the dissolution process and cation exchange reactions. Chemical reactions that may occur in the soil treated with lime and gypsum are: (1) The amounts of these sparingly soluble salts may be increased with the addition of water because of the solubility product principle and (2) Cation exchange reactions between solution cations occur because the relative activities of ions are altered by dilution. Adding water to surface-applied gypsum causes an exchange of adsorbed cations for Ca and the formation of an equivalent amount of SO_4 salts of other cations as follows (14,37,46,79,91):

$$\begin{aligned}&Y(Mg^{2+},\ 2Na^{+},\ 2K^{+}) + CaSO_4 \cdot 2H_2O + H_2O \longrightarrow \\ &Y(Ca^{2+}) + (Mg^{2+},\ 2Na^{+},\ 2K^{+}) + SO_4^{2-}\end{aligned} \tag{18}$$

where Y is the soil-exchange complex. With continued dilution, and further dissolution of gypsum, the reaction is governed by the cation exchange equilibrium, the solubility product, and the total amount of gypsum present (14,28,29).

Soil Factors Affecting Leaching of Ca^{2+}

Many of the conditions governing gypsum and lime reactions in soils, especially those influencing rate reactions and loss by leaching are not the same in tropical as in the temperate regions (72). General loss of Ca increases with increased rate of application. Amedee and Peech (8) defined Ca leaching as being proportional to $\theta/1-\theta$, where θ is degree of Ca saturation. In other words, the Ca concentration in solution is proportional to the degree of Ca saturation of the soil. Tinsley (92) reported that Ca from lime was tenaciously retained by the induced charges on the soils with large constant potential colloids than by the soils with predominantly constant charge colloids. He also reported that Ca from gypsum moved rapidly through the soil. In addition gypsum expelled more K into the soil solution than lime (28). This is explained by the additional charge density induced by increasing the pH by liming and Ca addition to the cation exchange that results in the explusion of K from the exchange complex.(7,52,53).

MATERIALS AND METHODS

Selected Physico-Chemical Properties of Soils of Malawi

Distribution of Soils of Malawi

The general description of the 10 soils from Malawi is presented in Table 1. Ultisols comprise by far the greatest proportion of cultivatable soils in the country and range in fertility status from high to very low (23,24). The other soil orders encountered to a lesser extent are Entisols and Inceptisols. The 10 soils included in this study consisted of eight Ultisols, an Entisol, and an Inceptisol. All were sampled from areas that currently produce either good or poor peanuts in both new and old establishments.

The A-p horizon of four soils were sampled from areas in the Central Region producing the bulk of the peanut crop, Nsaru, Lisasadzi, Kasiya, and Madisi and six were taken from the Northern Region where peanut production needs to be improved and expanded, at Baka, Mbawa, Euthini, Thulwe, Bapani, and Mjinge.

Climatic Variables

Malawi has a tropical continental climate with a single rainy season. The greater part of the Central Region receives from 75-100 cm of rainfall. In the Northern Region some areas along the shore of Lake Malawi receive from 170-230 cm of rainfall. Mean annual temperature range from 19 to 25°C depending on the altitude and distance from the Lake (23,24). The country experiences a dry cool season from May to August; a hot dry season from September to November, frequently con-

Table 1. General Description of the Ten Soils from the Northern and Central Region of Malawi.

Source(area)	Soil Order	Series	Parent Material	Drainage	Slope	Altitude Above Sea Level	Vegetation and Land Use
Thulwe	Ultisol	Kapemba sl	Basement complex and collovium.	Impeded site drainage	0°-2°	100-1200m	Savanna acacia & thicket. Corn, peanuts & fingermillet are dominant crops.
Euthini	Ultisol	Mperembe ls	Basement complex; biotite-feldspar, gneiss, and esine, quartz & garnet	fairly free,	gentle	100-1200m	Brachystegia woodland; cultivated with tobacco, fingermillet & grass
Bapani	Entisol	Kafukule cl	Basement complex rocks	free	gentle & moderate	1340-1523m	Brachystegia woodlands, sparsely cultivated with finger millet, peanuts, corn, grass and fodder crops.
Mjinge	Ultisol	Jandalala sl	Basement complex rocks granitic intrutions & colluvium	fair	<4°	1400-1500m	Brachystegia woodlands, cultivated to corn & peanuts
Mbawa	Ultisol	Loudon scl	Basement complex rocks, including feldspars, gneiss, quartz, hornblende & biotite	free	0°-1°	1220-1340m	Brachystegia woodlands, tobacco, corn, ground beans, soybeans, peanuts, fingermillet & grass

Table 1. Continued

Source(area)	Soil Order	Series	Parent Material	Drainage	Slope	Altitude Above Sea Level	Vegetation and Land Use
Baka	Inceptisol	Karonga cl	Alluvial and colluvium	Impeded site drainage	level lakeshore plain	460-550m	Acacia cultivated savanna, corn, cotton, peanuts millet & grass.
Lisasadzi	Ultisol	Kasungu s	Basement complex rocks	Site drainage is poor	gently undulating	1070-1220m	Brachystegia woodlands and acacia, corn, peanuts, tobacco, sweet potatoes & cassava are grown
Madisi	Ultisol	Chamama scl	Basement complex rocks of intermediate and basic composition	free	1°-3°	1130-1220m	Brachystegia woodlands and acia, corn, peanuts, tobacco, sweet potatoes & cassava are grown
Kasiya	Ultisol	Lilongwe sl	Basement complex rocks; hornblende & rich gneisses	free	0°-1°	1070-1220m	Cultivated savanna; corn, peanuts, beans, tobacco, sweet potatoes, grass & perennial fruit trees
Nsaru	Ultisol	Tembwe scl	Basement complex rocks	fairly well drained	0°-1½°	1100-1250m	Brachystegia woodlands; corn, peanuts, tobacco, sweet potatoes & grass

tinuing into early December, and a wet and hot season from December to March.

Mechanical Analysis

Particle size distribution of the soil samples was measured with a Bouyoucos Hydrometer (86) following soil dispersion with sodium hexametaphosphate (calgon).

Colloidal Analysis

Sample Preparation. Inorganic colloids from soils were separated from the silt and sand fraction by the general procedure of Jackson (49) which entails removal of multivalent cations and buffering the soil by washing with pH 5 NaOAc before removing the cementing agents of organic matter, and free Fe-oxides by wet oxidation with H_2O_2 and with dithionite-citrate in bicarbonate buffer (DCB), respectively. After dispersing the colloids by raising the pH to 10 with Na_2CO_3, the sand and clay fractions were separated by wet-seiving through a 300-mesh sieve and by repeated centrifuging at 1000 rpm for 2 minutes in an International No. 2 centrifuge and the residues being taken as the silt fraction. Organic matter was determined by wet digestion with $K_2Cr_2O_7$-H_2SO_4 (86).

X-ray Diffraction Analysis. X-ray diffraction analysis was used to identify the crystalline components of the inorganic colloids. The method consisted of plating duplicate 225-mg samples of the appropriate clay suspension on unglazed ceramic tiles according to the procedure of Rich (78) with one sample saturated with Mg and solvated with glycerol and another K saturated. X-ray diffractograms were obtained, on samples prepared in this manner, with a General Electric XRD 700 X-ray diffractometer using CuKα radiation and scanning 2θ from 2° to 30°. After the initial X-ray analysis, the K-saturated samples were heated to 550°C for 4 hours and rescanned. Quantitative analysis of the mineral content of the colloids was made with the aid of computer program by obtaining measurements of the peak intensities and areas of the respective diffractograms.*

Wet Chemical Analysis. The amounts of non-crystalline material in the colloidal fraction was determined by the method of Aleixiades and Jackson (6) involving selective dissolution with hot NaOH.

Chemical Analysis

Soil Acidity. Soil reaction was determined by measuring the pH of a 1:1 soil-solution suspension of either distilled water or N KCl using a Corning model 7 pH meter with a Sargent combination electrode. Differences obtained by substracting H_2O-pH from KCl-pH were expressed as ΔpH (86).

Total acidity was measured by equilibrating the soil with excess $BaCl_2$-triethanolamine (TEA) adjusted to pH 8.2 and back titrating an aliquot of the unreacted TEA-soil solution with standard HCl (86). Extractable acidity was determined by equilibrating the soil overnight with 100 ml N KCl and determining the amount of Al in the solution by titration.

Cation Exchange Properties. Soil CEC was determined by saturating with N NH_4OAc adjusted to pH 7.0, removing excess salt with C_2H_5OH, exchanging the retained NH_4 with N NaCl, and determining the NH_4 released by distillation into boric acid and back titrating with standard HCl (86). Exchangeable bases (Ca, Mg, K and Na) were measured in the NH_4OAc extract from the CEC determination. Calcium and Mg were measured by atomic absorption spectroscopy, and K and Na were measured by flame emission spectroscopy. Percent base saturation was obtained by dividing the sum of exchangeable bases by CEC as determined above, and multiplying by 100 (86).

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*Personal communications with Bill Pothier, technologist, Soils Department, University of Florida.

Zero Point of Charge (ZPC). The titration method of Van Raij and Peech ($\overset{93}{94}$), with the exception of the acid treatment, was used to determine the ZPC. The indifferent electrolyte NaCl was used at concentrations of 1N, 0.1N and 0.01N during the titrations. Following the addition of appropriate amounts of NaCl, 0.1N HCl or 0.1N NaOH in 100-ml stoppered polypropylene centrifuge tubes, distilled water was added to give a final volume of 20 ml and the desired concentration of NaCl. The pH of the solution was measured with a Corning model 7 pH meter with a Sargent combination electrode. Four grams of soil sample was introduced into the solution and incubated for 3 days with intermittent stirring. After the samples were centrifuged and the pH of the supernatant measured, the amount of H^+ or OH^- adsorbed was determined from the difference in pH between the equilibrated solution and the pH of the original solution. The values were converted to me/100g of sample and used for the net electrical charge.

The ZPC was obtained by plotting the H^+ and OH^- adsorbed (me/100g) against the pH of the equilibrium solution for each of the NaCl concentrations. The pH at which the curves for the NaCl curves intersected was taken as ZPC.

Calcium Adsorption Studies

The ability of the different soils to retain Ca was determined from adsorption isotherms obtained by equilibrating 10g of soil with 10 ml of solution containing 0, 10, 20, 50, 100, 200, 400 and 600 μg/ml Ca as $CaSO_4 \cdot 2H_2O$. The amount of Ca adsorbed (S), in μg/g was determined by the formula:

$$S = (C_i - C_e/m)v \qquad [19]$$

where C_i and C_e are initial concentration and equilibrium concentration after 30 minutes, respectively, v, mls of solution added and m the grams of soil added.

In an attempt to measure the absorption maxima of the soils 10 gm of soil was equilibrated for 30 minutes with a saturated solution of ^{45}Ca labeled $CaSO_4 \cdot 2H_2O$. After shaking for 30 minutes and centrifuging, a 5 ml aliquot was withdrawn and replaced with an equal volume of the original saturated solution, the sample was equilibrated again for 30 minutes, centrifuged and an aliquot withdrawn. This process was repeated seven times. The accumulative amount of Ca adsorbed by the soil was measured and plotted against the equilibrium concentration. The Ca concentration was determined via ^{45}Ca activity measured by Geiger Müler counter. Initial amounts adsorbed were calculated as above, additional amounts of Ca adsorbed was calculated by subtracting the total μg Ca in solution from the total μg Ca in the whole system.

Dissolution of Gypsum and Lime in Soil System

The Ap-horizon of Lakeland fine sand (Typic Quartzipsamment) Norfolk loamy fine sand (Typic Paleudult) and Red Bay fine sandy loam (Rhodic Paleudult) (Table 2) were incubated at room temperature and at

Table 2. Selected Chemical Properties of the Ap Horizon of Lakeland fs Red Bay fsl and Norfolk sl.†

	pH	Ca	Mg	K	CEC	O.M.
		-----------me/100g----------				--%--
Lakeland (lfs)	5.4	1.60	0.51	0.07	2.36	1.91
Red Bay (fsl)	4.2	0.60	0.30	0.10	8.70	4.30
Norfolk (sl)	5.4	1.00	0.50	0.50	3.00	1.09

†Cations were extracted with N NH_4OAc (pH 7).

field moisture content, with 0, 3000, 5000 μg/g soil $CaCO_3$ and 6000 μg/g soil $CaMg(CO_3)_2$. A year later, gypsum treatments of 0, and 5000 μg/g soil were imposed on 400 gm of each of the above air-dried samples to complete a 2x3x4 factorial in gypsum, soil and lime with two replications. The soils were incubated at 30% moisture in plastic bags at room temperature and 25 g sub-samples (on a dry weight basis) were taken at biweekly intervals for 6 weeks and then 4 weeks later the last samples were taken.

Calcium, K , Mg , SO_4 , pH and electrical conductivity (EC) were determined on the soil solution obtained by displacing the sample, in a .20 μ Nalge filter membrane, with 25 ml of deionized water. Calcium was determined both by the calcium selective electrode (CSE) and atomic absorption spectroscopy (AAS) for Ca^{2+} activity and total Ca, respectively. The $[Ca]$ total = $[Ca^{2+}] + [CaSO_4^{\circ}] + [CaCO_3^{\circ}] + [CaHCO_3^{+}]$, where bracket denote concentration. Magnesium was determined by AAS while K by flame emission. Sulphate determination was by the turbidimetric method of Tabatabai (89). Electrical conductivity and pH were determined by conventional method using conductivity bridge and pH meter, respectively. The Ca activity was obtained from standard curve obtained by plotting standard concentrations, ranging from 10^{-1} to 10^{-5} M $CaCl_2$, and 0 to 600 μg/ml Ca as $CaSO_4 \cdot 2H_2O$ against the potential in mV.

The solubility product of gypsum was calculated from the concentration of Ca and SO_4 by taking the Ca concentration as equal to that of total SO_4, because Ca was contributed by the solubility of $CaCO_3$, $CaMg(CO_3)_2$ and $CaSO_4 \cdot 2H_2O$.

Effect of Lime on the Movement of Gypsum

The purpose of top-dressing gypsum is to increase the Ca concentration in the fruiting zone. The author felt there was a need to investigate the effect of lime incorporated into the soil on the movement of surface-applied gypsum.

The Ap horizon of the Lakeland soil was air-dried and passed through a 2-mm sieve. Bulk samples were treated uniformly with 0, 200, 400 and 800 μg/g Ca as $Ca(OH)_2$ and equilibrated at 30% moisture for 6 weeks. Eight hundred grams of the air dried soil (bulk density 1.6) was placed in 5 x 25 cm column made from five sections of 5 x 5 cm polyvinyl chloride tubings joined together by paraffin wax and duct tape. The bottom of the column was glued to a lucite sheet with a 0.4 cm hole placed in the middle to carry a glass tubing attached to a Tygon tubing. This opening was covered with a filter paper and glass wool. After the soil columns were saturated with deionized water, from the bottom until the surface was just moist, 0, 200, 400 and 800 μg/g Ca from ^{45}Ca tagged gypsum ($CaSO_4 \cdot 2H_2O$) were evenly distributed on the surface of the columns to complete a 4x4 factorial in lime and gypsum, with two replication. The soil columns were covered with a piece of filter paper.

Leaching with 2.5 cm per day of deionized water at the slow rate 0.1cc/minute for a total of 80 cm was accomplished through a glass crucible holder, fitted with a rubber tubing carrying a pinch clap, suspended above each column.

Total Ca (^{40}Ca + ^{45}Ca), K, Mg, SO_4, pH and EC and ^{45}Ca activity were determined on the leachates collected daily. After 80 cm of water had been leached through the soil columns, they were taken apart at the 5-cm segments, the soil was air-dried and 5 g extracted with a 25 ml of 1N NH_4OAc (pH 7) and ^{45}Ca activity measured in the extract.

Total Ca and Mg were determined by atomic absorption spectroscopy, ^{45}Ca activity by Geiger Müller counter, SO_4 by the turbidimetric method of Tabatabai (89). Potassium was determined by flame emission spectroscopy. Electrical conductivity and pH were determined by convectional methods using the conductivity bridge and pH meter, respectively.

Greenhouse Experiment (1974)

Effect of Lime, Gypsum, Inoculum and Micronutrients on Peanut Plant Growth

In the winter of 1974 a greenhouse experiment was initiated to determine the effect of lime, gypsum, inoculum and micronutrients on the vegetative growth of peanuts. Pregerminated peanuts of the cultivar Florunner were planted three/pot in 3 kg of air-dried Lakeland fine sand soil collected from a peanut field which had received 2,200 kg/ha of lime, 200, and 300 kg/ha of NH_4NO_3 and 21-7-14 fertilizer, respectively.

Treatments consisted of five levels of $CaCO_3$ equivalent to 0, 250, 500, 1000 and 2000 ppm as $Ca(OH)_2$; uninoculated and inoculated on the seed. The $Ca(OH)_2$ was incorporated into the soil and moistened to field capacity prior to planting. Subplots were three treatments of Mn at

0, 5 and 20 ppm as $MnCl_2 \cdot 4H_2O$, two treatments of Cu at 0 and 5 ppm as $CuCl_2 \cdot 2H_2O$, two B treatments at 0 and 0.5 ppm as $NaBO_3 \cdot 4H_2O$ and two $CaSO_4 \cdot 2H_2O$ treatments at 0 and 50 ppm. These were applied in solution when the plants were 10 cm in height and thinned to 2 per pot. The treatments were replicated 3 times. A miticide (Calcon) was used to control mite. Plants were harvested after 80 days and the yield of tops, nutrient content of the tops and soil were determined.

Field Experiments

A total of four field experiments, three on a peanut farm in Williston and one on the University farm, were conducted to determine inoculum, lime, gypsum and fertilizer effects on the yield and quality of peanuts.

Field Experiment I (1974)

The experiment was carried out on a Lakeland fine sand. The soil had one crop of watermelon the year before the experiment otherwise it had been uncultivated. The experiment comprised a total of 21 treatments, in a randomized block design and was replicated 4 times. The main treatments were four levels of Mn, three rates of N, four rates of gypsum, and three rates of K each of S-coated K_2SO_4 and soluble-K_2SO_4, and two levels of inoculum (Table 3). All plots were 0.5 m x 6 m and received a basic application of 60 and 600 kg/ha of FTE 503 and 4-10-20 fertilizer, respectively. Florunner peanuts were planted in May 1974 in rows 0.5 m apart and on beds 1.0 m apart and carrying two rows. All plots were treated with nematicide (Nemagon), floridan, and Balan herbicide. The fungicide and insecticide treatments consisted of recommended rates of Bravo Benlate and Sevin commercial products.

Table 3. Treatments in Field Experiment I (1974) Conducted on Lakeland fine sand.

Treatment No.	Variables (kg/ha)†					Inoculation
	Mn	N	Gypsum	K		
				SCK	SK	
	---------------kg/ha-------------					
1	0	0	400	50	0	+
2	10	0	400	40	0	+
3	20	0	400	50	0	+
4	40	0	400	50	0	+
5	20	50	400	50	0	+
6	20	150	400	50	0	+
7	20	0	0	50	0	+
8	20	0	100	50	0	+
9	20	0	200	50	0	+
10	20	0	400	50	0	+
11	20	0	800	50	0	+
12	20	0	400	0	0	+
13	20	0	400	25	0	+
14	20	0	400	100	0	+
15	20	0	400	0	25	+
16	20	0	400	0	50	+
17	20	0	400	0	100	+
18	20	50	400	50	0	-
19	20	150	400	50	0	-
20	20	300	400	50	0	-
21	0	0	400	0	0	-

†Mn was as $MnSO_4$; N as NH_4NO_3, SCK and SK as sulfur coated K_2SO_4 and K_2SO_4, respectively; inoculated (+) and uninoculated (-).

Inoculum was dispersed into the seed drill by a gravity-fed Gandy applicator. All the other treatments, except gypsum, were broadcast by hand when the plants were a little over 3-weeks old. Gypsum was surface-applied when the plants started to bloom freely.

In September, the peanuts were lifted, picked from the vines by hand, and dried to approximately 7% moisture. Peanuts yields included weights of vines, pods and seeds. The tops were analyzed for Ca, Mg, K, Mn, Zn and Cu. Soil samples from each plot, composed of six plugs, 15 cm deep, were taken across harvested rows and analyzed for Ca, Mg, K, Zn, Cu, Fe and pH.

Field Experiment II (1974)

In June 1974, a second experiment was conducted at the Agronomy farm at the University of Florida, in Gainesville. The experiment was a 3 x 3 factorial experiment with cultivars and gypsum replicated 4 times in a complete randomized block design. Each plot was 6 m long comprised of 4 rows spaced 0.90 m apart. Seeds were planted 10 cm apart within rows. The field received 560 kg/ha of 2-8-16 fertilizer and 4 kg/ha Balan herbicides prior to planting. The cultivars were viz: Florunner, Florigiant and Early Bunch (UF 70015); and the gypsum rates were at 0, 800 and 1600 kg/ha. Gypsum was top-dressed to the fruiting zone when the plants were in early bloom. The peanuts were machine harvested and dried. The pods were picked from the vines, weighed and graded. Soil and plant samples were taken at harvest for nutrient content determinations.

Field Experiment III (1975)

In the spring of 1975 a third field experiment was conducted on the same peanut farm of the first 1974 experiment, except that the peanuts were planted in areas that had been in grass for 4 years prior to the experiment. The field had received 2200 kg/ha of lime, 670 kg/ha of 4-10-20 fertilizer; 60 kg/ha of micronutrient frit (FTE 503), and the recommended rates of Nemagon, Furidan and Balan, a nematocide, insecticide and herbicide, respectively. The Florunner peanuts were planted at the same spacing within and between rows as in 1974 except that the plots were 7.80 m long.

The 22 treatments, arranged in a complete randomized block design consisted of 3 rates of Mn, 3 levels of N, 4 rates of gypsum, 4 rates of K as S-coated K_2SO_4, as K_2SO_4 and KCl, and 2 rates of inoculum (Table 4). All treatments were applied as indicated in the preceding experiment.

In mid-September the whole peanut plant was harvested, dried, and the pods picked by a mechanical picker. Yields of vines and pods were determined and the samples graded. Plant and soil analysis were made as in the previous experiments.

Field Experiment IV

The fourth and last field experiment was conducted on the same farm location as the first and third field experiments. This experiment was a split plot design using four levels of dolomitic limestone $CaMg(CO_3)_2$ as main plots with seven subplot treatments of $CaSO_4 \cdot 2H_2O$ and $CaCl_2$.(anhydrous). The main plots were arranged in three randomized complete blocks. Treatments involved were $CaMg(CO_3)_2$ at 0, 1000, 2000, and 4000

Table 4. Treatments in Field Experiment III (1975) Conducted on Lakeland fine sand.

Treatment No.	Variables†						Inoculation
	Mn	Gypsum	N	K			
				SCK	SK	KCl	
	kg/ha						
1	0	0	0	0	0	0	+
2	0	400	0	0	0	50	+
3	10	400	10	0	0	50	+
4	20	400	10	0	0	50	+
5	10	400	100	0	0	50	+
6	10	400	200	0	0	50	+
7	10	400	0	0	0	50	-
8	10	400	100	0	0	50	-
9	10	400	200	0	0	50	-
10	10	400	0	25	0	0	+
11	10	400	0	50	0	0	+
12	10	400	0	100	0	0	+
13	10	400	0	0	0	0	+
14	10	400	0	0	25	0	+
15	10	400	0	0	50	0	+
16	10	400	0	0	100	0	+
17	10	0	0	0	0	50	+
18	10	100	0	0	0	50	+
19	10	200	0	0	0	50	+
20	10	400	0	0	0	25	+
21	10	400	0	0	0	100	+
22	0	0	0	0	0	0	-

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†See Table 1 for explanation of all variables except KCl.

kg/ha, gypsum ($CaSO_4 \cdot 2H_2O$) and $CaCl_2$ at 0, 200, 400, 800 kg/ha. Spacing between rows and within rows were similar to those in experiments I and III except the length of each plot was 3.6 m. Lime was disked into the soil before planting. Gypsum and $CaCl_2$ were top-dressed over the pegging zone of the Florunner variety, when the plants were in early bloom. All plots received recommended amounts of fungicides, insecticide, herbicides, micronutrients frit material and inoculum. Soil and plant samples (stems and leaves) were taken 3 times before harvest and at harvest. Peanuts were harvested by hand in September; yield of vines and pods were measured.

Plant Analysis

Samples were air dried at 60°C for 3 days and ground in a stainless steel mill to pass a 20-mesh screen. Two gram subsamples were ashed in a muffle furnace at 450°C for 2 hours or until ash was completely white in color. The ash was cooled and 20 ml of 5 $\underline{N}$ HCl were added. The solutions were evaporated to dryness on a waterbath to dehydrate silica. The residues were redissolved in 2.5 ml of 5 $\underline{N}$ HCl, brought to volume of approximately 20 ml with distilled water and heated to boiling. The solutions were filtered into 50 ml volumetric flasks and made to volume with distilled water. Calcium, Mg, Mn, Cu and Zn were determined by atomic absorption spectroscopy and K by flame emission spectroscopy.

Soil Analysis

The soil samples were air-dried and sieved for each of the experiments. In the greenhouse experiment 5-g samples were extracted with 25 ml of $\underline{N}$ NH_4OAc at pH 4.8 and double acid (0.05 $\underline{N}$ HCl and 0.025 $\underline{N}$ H_2SO_4) and the extract was analyzed for Ca, Mg, K, Mn, Cu and Zn as outlined in the plant analysis above. In addition, pH was determined in all soil samples.

In the third experiment, the soil samples were extracted by both N NH_4OAc (pH 7) and double acid. In the fourth experiments the soils were extracted with N NH_4OAc at (pH 7).

Peanut Grading

Peanuts were graded using regulation equipment specified by the State Federal Inspection Service. Two hundred gram peanut samples with an average moisture of 7% were taken from each treatment replication. Virginia pods, those riding 34/64 inch spaced rollers were separated on a presizer. Shelling weight is defined as the net weight of seed after shelling. Extra large kernels (ELK) are those riding 21 ½/64 inch diameter screens. Percent shrivels consist of the kernels not riding 16/64 inch diameter screens.

Statistical Analysis

Analysis of variance were computed for all field, greenhouse and laboratory experiments except in the experiment on leaching of gypsum and lime. Duncan's Multiple Range tests were used to compare differences between individual treatment means.

RESULTS AND DISCUSSION

Physical, Mineralogical and Chemical Analyses of Soils of Malawi

Physical Analyses

Particle Size Distribution and Organic Matter Content. Properties of the soil system are dependent on the physico-chemical properties of the organic and inorganic colloidal constituents of the clay fraction (92,97,98). The physical analyses and organic matter content (Table 5) indicate that among the eight Ultisols, the soil from Madisi and Lisasadzi had the lowest (53%) and highest (85%) percent sand, respectively; the clay fraction was lowest in the soil from Lisasadzi (5%) and highest in the soil from Madisi (37%) while organic matter was lowest in the soil from Euthini (0.53%) and highest in the soil from Madisi (5.30%). The Inceptisol (Baka) had 34, 37 and 2.62% sand, clay and organic matter, respectively and the soil from Bapani (Entisol) had 68, 24, and 1.55% sand, clay, and organic matter, respectively.

Particle size distribution and organic matter are important in that they influence the water-holding capacity and CEC of soils. Since CEC and water holding capacity increases with clay and organic matter content (47,98), the soils from Madisi and Baka have higher CEC and water holding capacity due to their relatively higher clay (37%) and organic matter content (5.30%), respectively. On the other hand, the soils with high percentage of sand and/or low clay or organic matter content necessitate higher fertilizer input to improve their fertility status. Another important characteristic that varies with texture is the N supply. Under

Table 5.--Particle Size Distribution and Organic Matter Content of the Surface Horizons of 10 Soils from Malawi.

Location of soil	Sand	Silt	Clay	O.M.	Texture
	%				
Thulwe (U)*	82	8	10	0.97	LS
Madisi (U)	43	14	33	5.30	SCL
Baka (I)	34	29	37	2.62	CL
Bapani (E)	68	8	24	1.55	SCL
Euthini (U)	82	7	11	0.53	LS
Mbawa (U)	69	9	22	1.24	SCL
Mjinge (U)	76	8	16	1.15	SL
Kasiya (U)	71	10	19	1.76	SL
Lisasadzi (U)	86	9	5	0.82	S
Nsaru (U)	62	10	28	2.49	SCL

* U, I and E indicate that soils from the location are representative of the Ultisol, Inceptisol and Entisol orders.

similar environment conditions, the availability of soil N to plants usually increases as the texture becomes finer. In topsoil, organic matter content and nitrogen status are closely related in Malawi soils (22,23,24). It is characteristic of Ultisols, excluding the soils from Madisi and Nsaru to have organic matter below 2%. All such soils will show responses to N fertilizers (22,23).

Colloidal Analyses

The X-ray diffractograms (Figures 1-5) indicate the occurrence of kaolinite as the dominant mineral of the clay fraction of all the soils except in the soils from Thulwe and Baka in which mica and montmorillonite, respectively, were dominant. The kaolinite mineral is well-crystallized as indicated by the sharp first and second order diffraction peaks at 7.2 and 3.6 A, respectively, which completely disappeared upon heating to 550°C. This mineral was most extensive in the soils from Mjinge and Kasiya. The second most common minerals were mica and quartz, indicated by diffraction peaks at 10 and 3.4 A, respectively. Mica occurred in the clay fraction of all soils except in those from Bapani and Nsaru; and was most extensive in the soil from Thulwe. Quartz was most extensive in the soils from Thulwe and Lisasadzi, the two soils with the lowest and highest amounts of clay and sand, respectively. The presence of montmorillonite is indicated qualitatively by X-ray diffraction peaks at 17.7 A in the soil from Baka (Figure 2) (49,94,98). Gibbsite is present in the soils from Mbawa and Mjinge and is qualitatively identifiable by the diffraction peaks at 4.8 and 4.4 A.

Quantitative Colloidal Analysis. An attempt was made to quantify each of the identified minerals on the basis of the total colloidal fraction of the soil. The analysis presented in Table 6, indicates the colloidal fraction of the soils from Baka comprised of approximately

Table 6.--Quantitative Estimates of Colloidal Components Based on the Total Colloid Content of the Surface Horizons of 10 Soils from Malawi.

Location	Colloids	O.M.	Fe_2O_3	Non-Cryst.	Mont.	Mica	Kaol-inite	Gibbsite	Quartz	Total
						%				
Thulwe	10	9.7	0.3	18	9	33	16	0	11	97.0
Madisi	33	16.1	0.4	11	0	10	65	0	8	110.5
Baka	37	7.1	0.2	10	43	26	12	0	11	109.3
Bapani	24	6.4	0.7	11	0	0	63	0	30	111.1
Euthini	11	4.8	0.4	11	0	14	68	0	12	110.2
Mbawa	22	5.6	0.4	8	0	17	56	8	12	107.1
Mjinge	16	7.1	0.3	9	0	6	76	4	6	108.4
Kasiya	19	9.2	0.3	8	0	9	76	0	5	107.5
Lisasadzi	5	16.4	0.4	9	0	25	47	0	12	109.8
Nsaru	28	8.8	0.4	8	0	0	81	0	10	108.2

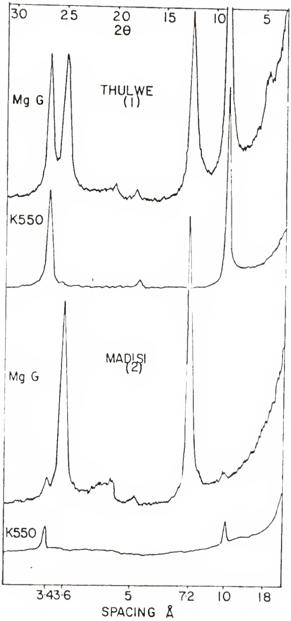


Fig. 1.--X-ray diffractograms of Mg and K saturated surface horizons of soils from Thulwe and Madisi.

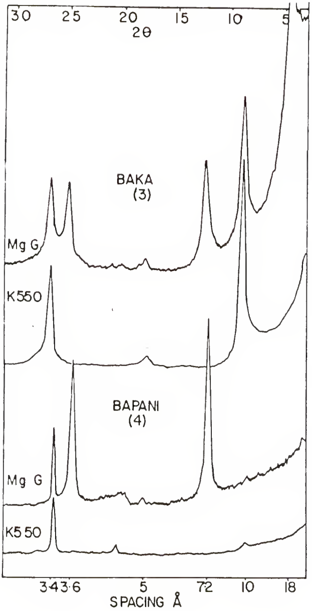


Fig. 2.--X-ray difrractograms of Mg and K saturated surface horizons of soils from Baka and Bapani.

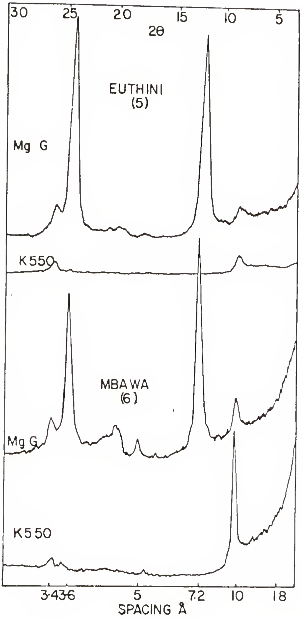


Fig. 3.--X-ray diffractograms of Mg and K saturated surface horizons of soils from Euthini and Mbawa.

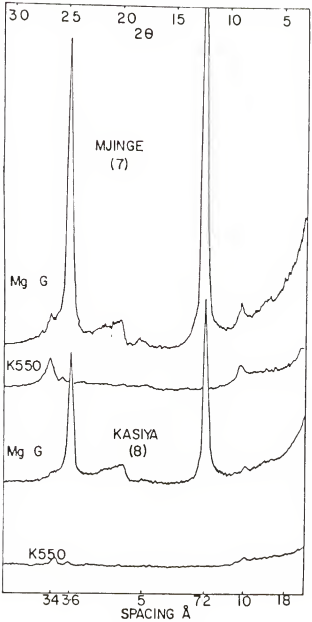


Fig. 4.--X-ray diffractograms of Mg and K saturated surface horizons of soils from Mjinge and Kasiya.

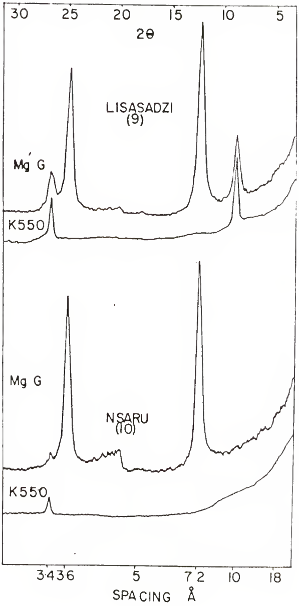


Fig. 5.--X-ray diffractograms of Mg and K saturated surface horizons of soils from Lisasadzi and Nsaru.

43, 26, 65 and 11% montmorillonite, mica, kaolinite, and quartz, respectively. In the colloidal fraction of the rest of the soils, with the exception of Thulwe, mica constituted 33% of the colloidal fraction and kaolinite averaged more than 60%. Quantitatively organic matter was fourth in abundance, after kaolinite, mica and quartz. It was highest in the colloidal fraction of the soils from Madisi and Lisasadzi with 16.1 and 16.4% present, respectively. There was little variation in the amounts of Fe_2O_3 and non-crystalline material among soils and Fe_2O_3 ranged from 0.3 to 0.7% and non-crystalline material from 8 to 18%, respectively.

The physico-chemical properties of the colloidal fraction containing kaolinite, montmorillonite and mica are dominated by these minerals and reflect properties of constant-charge colloidal surfaces. On the other hand, since organic matter, Fe-oxides, and gibbsite are generally all colloids with constant potential and their presence is low in Malawi soils, it is expected that constant potential surfaces are not as dominant as constant-charge colloidal surfaces in these soils. Therefore, a very little change in CEC of these soils is expected with increase in pH (52,53).

With the exception of the soil from Baka and Thulwe (12 and 16%), Ca applied to these soils should be readily available for the developing peanut fruit since kaolinite is the dominant mineral, according to Allaway (7), Mehlich and Colwell (59), and Mehlich and Reed (60).

Chemical Analyses

Soil Reaction. The soil reaction (Table 7) measured in distilled water indicated all the soils to be acidic but none were below pH 5.0

and only 2 soils (Mbawa and Mjinge) had pH below 5.5 and none was above pH 6.4. Since harmful acidity exists only below pH 5.5 (91,92), only soils from Mbawa and Mjinge will benefit from a pH adjustment in neutralizing monomeric Al^{3+} and H^+. Liming is beneficial for peanut growing in that Ca added will not be adsorbed by the soil. This is probably true because of little increase in CEC due to adsorption of OH^- by these soils is expected since these soils were not dominated by constant-potential colloids (52,53,92).

The addition of a non-specific electrolyte (KCl) decreased the pH by 0.43 to 1.00 units. With constant-charge colloids, as we have in this case, the increase in ionic strength produced by the addition of an electrolyte must be accompanied by a reduction in potential in order for the surface charge to remain constant (52,53). Consequently the addition of KCl reduces the pH by exchanging K for the H^+ and Al^{3+} ions retained in the double layer. This forces the reduction in surface potential and depresses the double layer thickness according to the formula:

$$\sigma = \frac{K\varepsilon}{4\pi}\psi \qquad [20]$$

where K is the reciprocal of the double layer thickness, and depends on the salt contentration, σ is the surface charge, ψ the potential, and ε is the dielectric constant of the medium.

The ΔpH values obtained are all negative and indicate that all the soils had a negatively charged surface (52,53,92).

Total Acidity. The $BaCl_2$-TEA (pH 8.2) neutralized the maximum measured acidity from all 10 soils (Table 7). The values ranged from 2.41 to 12.10 meq/100g with the maximum extracted from the soil from

Madisi and lowest from the soil from Thulwe which have 5.30 and 0.97% OM, respectively. This is an indication that OM is a source of acidity due to the dissociation of Al^{+3} from the functional groups in the organic fraction of the soil. This release of Al^{3+} is pH-dependent since the extraction was at pH 8.2. The increase of $BaCl_2$-TEA acidity with organic matter is indicated by the significance of the R^2 value shown in Table 8.

Extractable Acidity. Because N KCl is a neutral unbuffered electrolyte, it extracts only exchangeable H^+ and Al^{3+} ions from the exchange complex and does not become involved in the surface adsorption of potential determining ions. The KCl-extracted acidity is solely due to Al^{3+} and ranged from 0.10 to 0.30 me/100g (Table 7). Since H^+ is rarely present in the exchange sites unless the soil pH is below 5.5, only two of these soils fall under this category, and these are soils from Mbawa and Mjinge with pH of 5.42 and 5.32, respectively. Malawi soils can benefit from lime application as a source of readily available Ca.

Cation Exchange Capacity and Exchangeable Cations. The CEC determined by NH_4OAc (pH 7.0) for the 10 soils ranged from 2.60 me/100g in the Euthini soils to 21.18 in the Baka soil. The sum of exchangeable bases varied from 1.63 in the soil from Mjinge to 17.71 me/100g in the soil from Baka, (Table 9). Exchangeable Ca and % Ca saturation were significantly dependent on CEC (Table 8) while CEC was significantly dependent on OM content. The Ca saturation ranged from 29.1% in soil from Mjinge to 55.6 in the soil from Baka and the % base saturation was lowest in the soil from Mbawa (44.5%) and highest in the soil from Baka (83.6%). Both % Ca saturation and base saturation are

Table 7.--Soil Reaction and Acidity Measurements of Surface Horizons from 10 Soils of Malawi.

Location of soil	pH		ΔpH	Acidity			
	H_2O	KCl	$KCl-H_2O$	$BaCl_2$ -TEA	Titration H	Titration Al	CEC
				---------- meq/100 g soil	----------	----------	----------
Thulwe	6.37	5.37	-1.00	2.41	0	0.25	3.78
Madisi	5.96	5.41	-0.55	12.10	0	0.10	19.43
Baka	5.98	5.26	-0.72	10.13	0	0.10	21.18
Bapani	6.35	5.86	-0.49	6.08	0	0.10	5.24
Euthini	6.26	5.67	-0.59	3.24	0	0.10	2.60
Mbawa	5.42	4.71	-0.71	6.84	0	0.10	5.28
Mjinge	5.32	4.89	-0.43	5.27	0	0.30	3.26
Kasiya	6.03	5.53	-0.50	5.48	0	0.20	7.27
Lisasdzi	6.16	5.68	-0.48	2.83	0	0.13	2.85
Nsaru	5.58	5.02	-0.56	10.33	0	0.13	10.16

Table 8. Linear Regression Between CEC, Organic Matter, Exchangeable Ca, and Exchangeable Mn.†

Regression variables X	Y	R^2
CEC	Exchangeable Ca	0.64**
CEC	% Ca sat.	0.22*
OM	CEC	0.72**
OM	Extractable Mn	0.33**
OM	$BaCl_2$ TEA	0.76**

†Regression significant at 5% (*) and 1% (**)

not good indicators of total Ca and total cations present in the soil because both values depend on the CEC. Percent Ca saturation is important for peanuts because it is a direct measure of the available Ca in the soil, in relation to other cations.

Foster (38) did not obtain peanut yield response to Ca application in soils with mean exchangeable Ca values in excess of 12 me/100g. If this is correct then only soils from Madisi and Baka might not respond to Ca application. As a matter of fact, peanuts grown in these soils do very well without Ca application. Amedee and Peech (8) defined Ca leaching losses as proportional to the degree of Ca saturation. Since none of these soils have values above 60% Ca saturation, loss of Ca due to leaching is minimal but leaching will be enhanced if too much Ca is applied in soils having low CEC values such as soil from Lisasadzi, Mjinge, Mbawa, Euthini, Bapani, and Thulwe.

With the exception of the soils from Madisi and Nsaru, levels of Mn, Fe, Zn and Cu contents were in ranges from 46 to 96, 10 to 22, 17 to 29, and 0.3 to 1.5 ppm, respectively (Table 10). The higher amounts of

Table 9.--Exchangeable Bases, Ca Saturation, and Base Saturation of Surface Horizons of 10 Soils from Malawi.

Location of soil	Exchangeable bases Ca	Mg	Na	K	Sum	Ca sat.	Base sat.
	--------------meq/100 g soil	------------				---------%---------	
Thulwe	1.58	0.52	0.04	0.55	2.69	41.79	71.16
Madisi	9.15	2.64	0.02	0.47	10.28	47.09	52.91
Baka	11.78	4.68	0.24	1.01	17.71	55.62	83.62
Bapani	2.60	0.76	0.02	0.47	3.85	49.62	73.47
Euthini	1.14	0.34	0.01	0.38	1.87	43.84	71.90
Mbawa	1.55	0.71	0.02	0.17	2.35	29.36	44.51
Mjinge	0.95	0.37	0.04	0.27	1.63	29.14	50.00
Kasiya	2.93	0.97	0.02	0.54	4.45	40.30	62.72
Lisasadzi	1.38	0.73	0.01	0.15	2.28	48.42	80.00
Nsaru	3.59	3.12	0.02	0.16	6.89	35.33	67.82

Mn in the soils from Madisi and Nsaru, 114 and 121 ppm, respectively, are due to the higher organic matter content in these soils which has a bearing on the Mn content as evidenced by the significant R^2 value for this relationship given in Table 7 (77).

Supplementary Soil Properties

Zero Point of Charge. The ZPC values of the 10 soils from Malawi ranged from 3.5 to 5.5 (Table 11 and Figures 6-8) and were below the respective pH values determined in water. It follows from equation [2] page 17, that if the soil pH is higher than the pH at the ZPC, the soil material has a net negative charge (cation exchanger) and the pH in N KCl is lower than that in water (52,53). These results indicate that the soils had a net negative charge and the shift of the ZPC to a positive value indicates the dominance of the permanent charges (Figure 6-8). Because these soils have dominantly permanent charge colloids the ZPC does not adequately define the charge characteristic (52,92). The slopes of the σ_0-pH curves give a good indication of the buffering capacity of a soil (53). If σ is expressed as me/100g soil of H^+ or OH^- the slope becomes steeper as % clay increases. Steep slopes were noted in soils from Baka, Madisi, Nsaru, and Kasiya which have 37, 33, 28 and 19% clay, respectively and 11.78, 9.15, 3.59, and 2.93 me/100g Ca, respectively. According to Keng and Uehara (53), the buffering capacity (the steepness of the σ_0-pH curves) increases with increasing Ca concentration. With constant potential colloids, Keng and Uehara (52) suggest that $Ca(OH)_2$ or $CaCO_3$ are not particularly efficient chemicals for increasing the soil solution pH and that Ca in the Stern layer is held with some affinity, and therefore not readily exchangeable.

Table 10.--Micronutrients Extracted by Double Acid Method from the Surface Horizons of 10 Soils from Malawi.

Soil location	Micronutrients Mn	Cu	Fe	Zn
	--------ppm--------			
Thulwe	46	.5	10	17
Madisi	114	.3	4	10
Baka	63	1.5	22	29
Bapani	96	1.0	13	24
Euthini	78	.8	15	19
Mbawa	73	1.0	13	27
Mjinge	64	.8	17	28
Kasiya	89	1.3	13	17
Lisasadzi	75	.8	15	17
Nsaru	125	1.5	10	6

Table 11. ΔpH as a Measure of the Net Charge.

Soil Location	ZPC	pH KCl	pH_2O	ΔpH
Thulwe	4.6	5.4	6.4	-1.0
Madisi	4.9	5.4	6.0	-0.6
Baka	5.0	5.3	6.0	-0.7
Bapani	5.5	6.9	6.4	-0.5
Euthini	4.3	5.7	6.3	-0.6
Mbawa	4.1	4.7	5.4	-0.7
Mjinge	3.5	4.9	5.3	-0.4
Kasiya	4.2	5.5	6.0	-0.5
Lisasadzi	3.5	5.7	6.2	-0.5
Nsaru	4.2	5.0	5.6	-0.6

Soils with steep σ_0-pH curves and ZPC values below pH 5, generally do not need to be limed above pH 6. However, the pH values should be maintained above the ZPC to reduce leaching losses of nutrient cations (52,53).

The change in CEC with increasing pH differed among soils due to the nature of the soil colloid. The higher the clay content (higher surface area), the greater the oxide content, and the higher the OM content the greater must be the increase in CEC for a unit change in pH above the ZPC depending on the clay components (52,53,92). Further, at a given pH above the ZPC, more Ca is adsorbed than N or K.

Calcium Adsorption

Mehlich and Colwell (59) and Mehlich and Reed (60) found that the concentration of soil solution Ca was dependent on the type of colloid dominant in the soil. At equal rates of Ca application the concentration of soil solution Ca^{2+} was greater in a colloid system dominated by kaolinitic type than in those dominated by montmorillonitic or organic

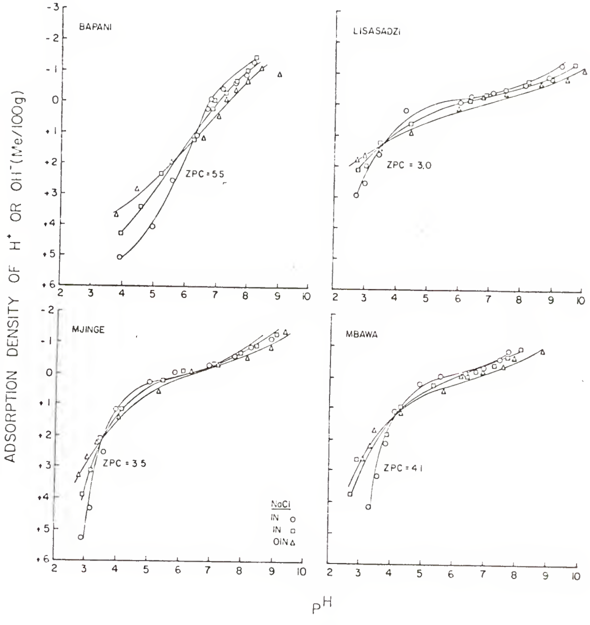


Figure 6. Zero point of charge levels found by titration of the Ap horizon of soils from Bapani, Lisasadzi, Mjinge, and Mbawa.

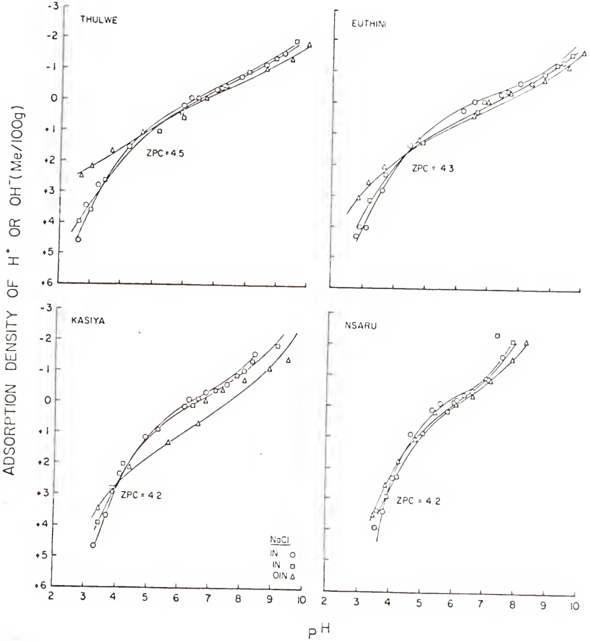


Figure 7. Zero point of change levels found by titration of the Ap horizons of soils from Thulwe, Euthini, Kasiya, and Nsaru.

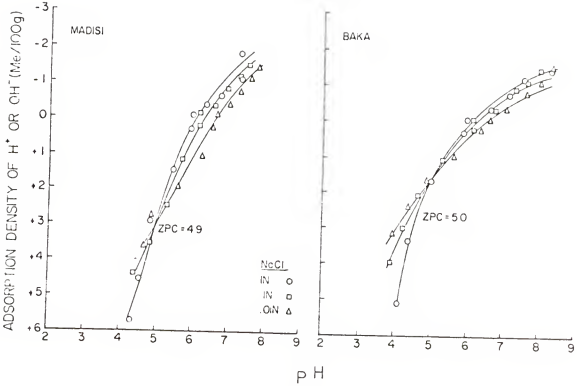


Figure 8. Zero point of charge levels found by titration of the Ap horizons of soils from Madisi and Baka.

colloids. They attributed this observation to the position of the charge on the colloids. In the montmorillonitic and organic colloids, the charges, besides being larger, are mainly intracellular resulting in Ca^{2+} being tenaciously bound. In the kaolinitic type of colloids, the charges being much less, are mainly extracellular, and the Ca^{2+} is not held so tight and therefore a greater proportion is in the solution phase. When peanuts were grown in these colloids, their yield and quality in the kaolinitic type of colloids were superior with dominantly montmorillonitic and organic colloids.

The adsorption isotherms for the ten soils from Malawi (Figure 9) indicate that the soils from Madisi, Baka, Nsaru and Kasiya, in spite of having high exchangeable Ca, 9.15, 11.78, 3.59, and 2.93 me/100g, respectively, adsorbed more Ca^{2+} than the other 6 soils. Since these soils have CEC values of 19.43, 21.18, 10.16, and 7.27 me/100g, respectively, they should absorb more Ca^{2+}. The rest of the soils (Bapani, Mbawa, Lisasadzi, Thulwe, Euthin and Mjinge) adsorb less Ca^{2+} simply because they possess lower CEC values.

An attempt was made to determine the Ca^{2+} adsorption maxima for the ten soils and the results (Figures 10-12) show similarity to the above results in that the soils from Madisi, Baka and Nsaru adsorbed much more Ca^{2+} than the others. The soils from Bapani, Lisasadzi, Mjinge, Mbawa, and Euthini reached adsorption maxima when 400 μg/g of Ca^{2+} (2 me/100g) were adsorbed. The soils from Madisi and Baka, however, did not approach adsorption maxima even after adsorbing an excess of 1600 μg/g (8 me/100g) of Ca^{2+}, while the soils from Kasiya, Thulwe and Nsaru attained maxima at 400, 600 and 800 μg/g of Ca^{2+} or 2, 3, and 5 me/100g of Ca^{2+}, respectively.

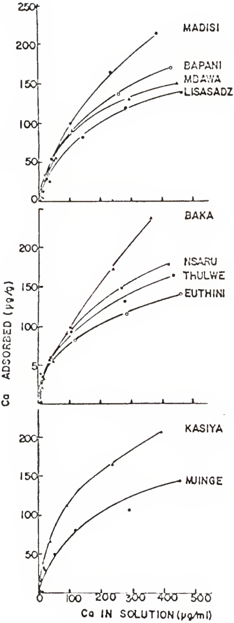


Figure 9. Ca adsorption isotherms of the Ap horizon of the ten soils of Malawi.

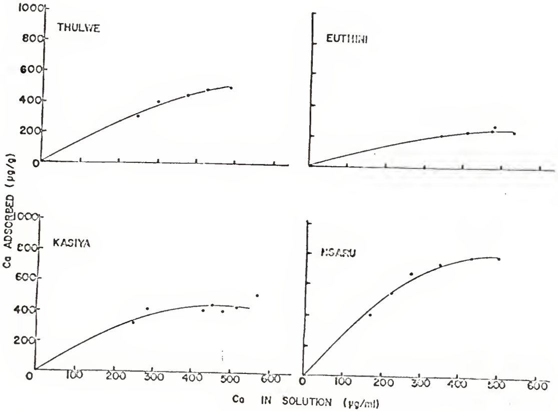


Figure 10. Ca adsorption isotherm of the Ap horizon of the soils from Thulwe, Euthini, Kasiya, and Isaru.

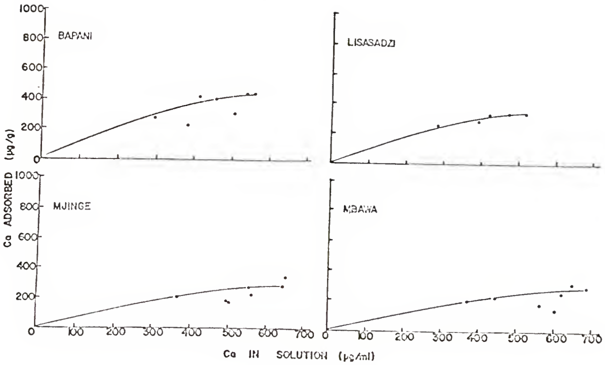


Figure 11. Ca adsorption isotherm of the Ap horizon of soils from Bapani, Lisasadzi Mjinge, and Mbawa.

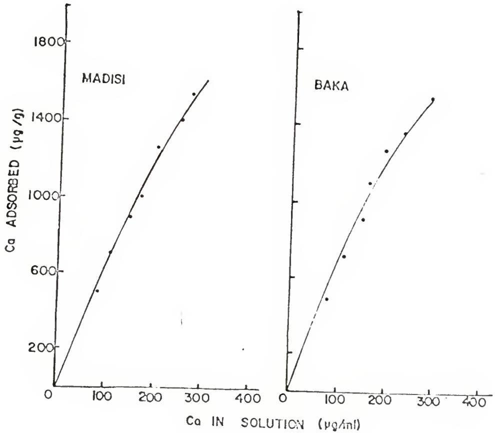


Figure 12. Ca adsorption isotherm of Ap horizon of soils from Madisi and Baka.

The differences described above are attributable to CEC, clay and organic matter content, and type of colloid dominant in the soil system. The soils from Madisi and Baka, with the highest CEC values of 19.43 and 21.18 me/100g, respectively, adsorbed the highest amounts of Ca^{2+}. The higher Ca adsorption of soils from Madisi and Baka is because of the relatively higher CEC of these soils which is contributed by organic matter in the former and montmorillonite in the latter. The rest of the soils dominated by kaolinite, adsorb less Ca because the bonding energy of kaolinite for Ca is low.

The rates of lime and gypsum required for adequate Ca for peanut production differs so that in the soils with high Ca affinity (Baka and Madisi) high lime and gypsum inputs are required to provide the necessary amount of Ca. On the other hand, lower rates are needed for the rest of the soils (Thulwe, Euthini, Bapani, Mbawa, Mjinge, Kasiya and Lisasadzi). Too high rates in these soils can result in much of the Ca being lost due to leaching.

Laboratory Experiments

Dissolution of Lime and Gypsum in the Soil

The effectiveness of lime and gypsum in peanut production depends on Ca level in the soil solution which determines the maximum production of yield and quality of peanuts. Since lime application precedes gypsum, it was postulated that the lime could adversely affect the solubility of the surface-applied gypsum. Furthermore if lime provides adequate Ca then gypsum top-dressing becomes unnecessary. The concentration of total Ca, total SO_4, active Ca^{2+}, pH and EC were significantly affected by rates of lime, gypsum, soil type, and time of incubation (Table 12). Lime, gypsum, soil type and time interacted significantly. The means upon which the analyses were based are presented in Table 13. The Asp for gypsum though slightly lower than the literature value of 2.45 x 10^{-5} M/liter ranged from 1.43 to 2.09 x 10^{-5} M/liter at 0 and 5000 µg/g $CaCO_3$, respectively; and 1.78 x 10^{-5} M/liter at 5000 µg/g $CaMg(CO_3)_2$. Soil type had no significant effect on the Asp value which was 1.72, 1.51 and 2.13 x 10^{-5} M/liter in Norfolk, Red Bay, and Lakeland soil, respectively. However, the total electrolyte concentration, as determined by the E.C. values, was highest in the Red Bay soil.

The lime x gypsum interaction (Table 14) clearly indicates that gypsum contributed a much higher concentration of soluble Ca than either $CaCO_3$ or $CaMg(CO_3)_2$. In the absence of gypsum, active Ca^{2+} concentration was 26.0, 58.9, 55.0 and 26.0 µg/ml at 0, 3000, 5000 µg/g $CaCO_3$ and 5000 µg/g $CaMg(CO_3)_2$, respectively. In the presence of gypsum the concentration was 206.2, 231.2, 247.5 and 161.5 µg/ml at 0, 3000, 5000 CaCO and 5000 µg/g $CaMgCO_3$, respectively. Total Ca in solution behaved similarly. The Ca concentration increases with both gypsum and lime application and with their dissolution. These data presented above seem to indicate that Mg^{2+} from $CaMg(CO_3)_2$ represses the activity of Ca^{2+} in the soil solution regardless of the presence or absence of gypsum.

The soil solution pH was significantly affected by the gypsum x lime interaction. The acidifying effect of gypsum was reduced in the presence of lime [$CaCO_3$ and $CaMg(CO_3)_2$].

Table 12. Analysis of Variance of Soil Solution Data for the Dissolution of Lime and Gypsum in Lakeland fs, Red Bay fsl, and Norfolk lfs.†

Source	df	Active Ca^{2+}	Total Ca	Total SO_4	pH	EC	Asp†
		----------mean squares----------					
Blocks	1	9366.05*	178364	71959	0.06	0.59*	1.18
Lime (L)	3	34310.23**	410031**	58502	9.29**	0.26	1.82
Gypsum (G)	1	1390431.90**	12911688**	28056386**	5.94**	73.22**	
L x G	3	7196.73*	253688**	83629	1.32**	0.26	
Soil (S)	2	19395.57**	563808**	114399	1.36**	0.55**	3.20
L x S	6	445.04	31467	6327	0.54	0.04	0.07
G x S	2	21360.29**	605114**	152509*	0.12	0.61**	
L x G x S	6	525.76	30610	3627	0.09	0.02	
Error (a)	23	1967.23	43564	33788	0.22	0.09	0.84
Time (T)	3	19995.42**	2402272**	64437*	0.65**	0.16	0.23
L x T	9	7254.65**	199057**	52357*	0.47**	0.17	0.79
G x T	3	6630.98**	2289216**	11298	0.04	0.09	
L x G x T	9	3941.57**	183146**	34324	0.07	0.12	
S x T	6	2603.71*	286899**	27216	0.16	0.13	0.64
L x S x T	18	1080.09	33193	24290	0.09	0.09	0.55
G x S x T	6	1815.45	276130**	30242	0.10	0.06	
L x G x S x T	18	850.55	33541	26433	0.06	0.09	
Error	72	938.86	41904	20969	0.15	0.07	0.43

*Significant at the 5% level

**Significant at the 1% level

†Mean squares must be multiplied by 10^{-5}. Degrees of freedom for Error (a) and Error (b) are 11 and 36, respectively.

Table 13. Soil Solution Data Measurements for the Dissolution of Lime and Gypsum in Lakeland fs, Red Bay fsl, and Norfolk lfs.[†]

Treatment	Active[‡] Ca^{2+}	Total[§] Ca	Total SO_4	Asp	EC	pH
	----------μg/ml---------			x10^{-5}M/liter	(mmhos/cm)	
$CaCO_3$(ppm)						
0	116	174	456	2.09	1.02	6.2
3000	151	227	451	1.87	1.12	7.1
5000	145	218	378	1.43	0.97	6.9
$CaMgCO_3$(ppm)						
5000	94	141	422	1.78	0.95	7.2
Gypsum(ppm)						
0	42	63	45	--	0.39	7.0
5000	212	218	809	--	1.63	6.7
Soil						
Norfolk lfs	126	189	421	1.72	1.06	6.7
Red Bay fsl	109	164	388	1.51	1.91	6.9
Lakeland fs	144	216	472	2.13	1.08	7.0
Time(days)						
14	145	216	456	1.88	1.06	7.0
28	142	190	398	1.86	0.95	6.8
42	118	182	462	1.73	0.98	6.9
70	102	156	393	1.69	1.06	6.7

[†] Lime, gypsum, soil and time means are averages of 48, 96, 64, and 48 observations respectively.

[‡] Active Ca^{2+} was determined by Ca selective electrode.

[§] Total Ca was determined by atomic absorption spectroscopy.

Table 14. The Effect of Lime x Gypsum Interaction on Ca Concentration and pH of Soil Solution.

		$CaCO_3$		$CaMg(CO_3)_2$	
	ppm				
$CaSO_4 \cdot 2H_2O$ (ppm)	0	3000	5000	5000	Equation†
		Active Ca^{2+}‡ (μg/ml)			
0	26.0b*	58.9b	55.0b	26.0b	30.03 + 6.22L
5000	206.2a	231.5a	247.4a	161.5a	206.33 + 8.8 27L
		Total Ca§ (μg/ml)			
0	28.5b	58.3b	76.4b	30.5b	N.S.
5000	309.4a	347.2a	371.6a	242.2a	309.2 + 38.04L
		pH			
0	6.64a	7.07a	7.15a	7.31a	6.67 + 0.1046L
5000	5.80b	6.81a	7.07a	7.07a	$5.81 + 0.46L - 0.42L^2$

*Values in column for each lime level not followed by the same letter are significantly different at 5% level.

†$L = \frac{CaCO_3}{1000}$

‡Active Ca^{2+} determined by Ca selective electrode.

§Total Ca determined by atomic absorption spectroscopy.

the pH was 6.64, 7.07, 7.15 and 7.31 at 0, 3000, 5000 μg/g $CaCO_3$ and 5000 μg/g of $CaMg(CO_3)_2$, respectively, while in the presence of 5000 μg/g of gypsum pH was 5.80, 6.81, 7.07, and 7.07 at 0, 3000, 5000 μg/g of $CaCO_3$ and 5000 μg/g of $CaMg(CO_3)_2$, respectively. The final effect of gypsum in acid soils is to lower the pH slightly. Therefore, in soils with optimum pH but with low Ca for production of maximum yield and quality of peanuts, gypsum application would be more beneficial.

Soil solution concentration of Ca^{2+} and EC levels contributed by gypsum were significantly affected by the type of soil (Table 15). At 5000 μg/g sypsum the soil solution Ca^{2+} determined by selective electrode was 203.9, 181.0 and 250.0 μg/ml in the Norfolk, Red Bay, and Lakeland soil, respectively. The EC was 1.63, 1.46 and 1.81 mmhos/cm in Norfolk, Red Bay, and Lakeland soil, respectively. The Ca^{2+} concentration and EC followed the order of the present sand in the soils: Lakeland > Norfolk > Red Bay. The Red Bay soil because of its higher clay content, higher CEC (8.70 me/100g) and low initial Ca content (0.60 me/100g) tends to remove Ca^{2+} from the soil solution. The Lakeland soil, with low CEC (2.36 me/100g) and higher initial Ca content (1.60 me/100g) does not remove as much Ca^{2+} from the soil solution. The Norfolk soil with intermediate CEC and Ca values gives soil solution with intermediate Ca^{2+} concentration and EC, between those of other two soils. Generally total salts are greater in sandy soils than in clay soils at equal fertilizer inputs, probably because of prevailing cation exchange reactions (54).

First-order lime x time interactions were significant, included for Ca^{2+} and SO_4^{2-} concentration, pH, and EC (Table 16). The Ca activity and total Ca decreased with time at all levels of $CaCO_3$ and $CaMg(CO_3)_2$

Table 15. Soil Solution Concentration of Ca , and EC as a Response to Gypsum x Soil Interaction.

Gypsum (ppm)	Soil Norfolk lfs	 Red Bay fsl	 Lakeland fs
		Active Ca$^{2+‡}$ (µg/ml)	
0	48.5a*	37.6a	38.2a
5000	203.9b	181.0b	250.0a
		Total Ca† (µg/ml)	
0	46.7a	50.2a	37.4a
5000	305.9b	271.5b	375.0a
		EC (mmhos/cm)	
0	0.49a	0.35a	0.35a
5000	1.63b	1.46b	1.81a

*Values in horizontal rows not followed by the same letter are significantly different at 5% level.

†Active Ca^{2+} determined by Ca selective electrode.

‡Total Ca determined by atomic absorption spectroscopy.

Table 16. Soil Solution Concentration of Active Ca^{2+}, Total Ca, Total SO_4, pH and EC as a Response to Lime x Time Interaction.*

Response	Time		$CaCO_3$(ppm)		$CaMgCO_3$(ppm)	
	(days)	0	3000	5000	5000	Equation
Active Ca^{2+}† (μg/ml)	14	121.8	172.2	167.5	118.2	$121.75 + 28.36L^{*} - 3.84L^2$
	28	100.8	186.8	153.1	125.2	$100.83 + 55.99L - 9.11L^2$
	42	109.0	131.8	153.4	78.1	$107.97 + 8.78L$
	70	132.7	90.0	130.9	53.3	$132.67 - 35.03L + 6.94L^2$
Total Ca‡ (μg/ml)	14	200.0	216.8	251.8	196.4	N.S.
	28	198.8	154.1	244.9	162.5	N.S.
	42	177.3	194.9	227.7	128.4	N.S.
	70	199.1	135	196.4	80.0	$199.0 + 52.5L$
Total SO_4 (μg/ml)	14	440.0	417.4	410.1	554.5	N.S.
	28	432.5	319.8	428.4	412.5	$432.50 - 92.66L + 18.37L^2$
	42	463.3	499.6	498.3	435.8	N.S.
	70	487.1	332.1	466.7	284.6	$459.10 - 37.23L + 6.07L^2$
pH	14	6.46	7.07	7.43	7.12	$6.4695 + 0.1944L$
	28	6.29	6.92	7.11	6.98	$6.3316 + 0.1670L$
	42	6.14	7.13	6.96	7.27	$6.1408 + 0.5792L - 0.0830L^2$
	70	6.00	6.63	6.93	7.40	$6.0236 + 0.1871L$
EC (mmhos/cm)	14	0.96	0.99	1.08	1.20	N.S.
	28	0.95	0.81	1.09	0.95	$0.9517 - 0.1584L + 0.0371L^2$
	42	0.98	1.01	1.12	0.79	N.S.
	70	1.17	1.05	1.17	0.86	N.S.

*Means are averages of 12 observation consisting of 3 soils, 2 gypsum levels, and 2 replications.
†Active Ca^{2+} determined by Ca selective electrode.
‡Total Ca determined by atomic absorption spectroscopy.

except at zero lime when Ca^{2+} activity increased from 121.8 to 132.7 μg/ml at 14 and 70 days respectively and total Ca did not change (200.0 to 199.1 μg/ml at 14 and 70 days, respectively). This decrease with time was more drastic with $CaMg(CO_3)_2$. There was a cubic relationship between Ca^{2+} activity and $CaCO_3$ application at all times, except at 42 days when the relationship was linear.

No identifiable trends were noticeable with changes in SO_4^{2-} concentration except at 28 and 70 days there was a significant cubic regression with rates of $CaCO_3$ probably as a result of the exclusion of the $SO_4^{=}$ from the soil exchange reactions.

The failure of the Ca concentration to reach equilibrium by 14-28 days could be attributed to air exposure and uncontrolable temperature variations during the time of incubation.

Electrical conductivity was determined by the concentration of Ca^{2+}, K^{+}, Mg^{2+}, and SO_4^{2-}. Without lime, SO_4 concentration varied from 440.0 to 487.1 μg/ml only after 14 and 70 days, respectively while EC changed from 0.96 to 1.17 mmhos/cm, respectively during this period. The decrease in total SO_4 concentration and EC with time in the presence of dolomite is probably a result of increase in the Mg^{2+} concentration which represses the activity of both Ca and SO_4.

It is evident that gypsum ($CaCO_4 \cdot 2H_2O$) provides a much higher concentration of Ca^{2+} than lime [$CaCO_3$, and $CaMg(CO_3]_2$ because of its higher solubility. Lime application will benefit peanuts because it increases soil pH and soil Ca. In fine-textured soils, with high organic matter, high CEC and low Ca content, gypsum application is beneficial because it supplies much higher levels of Ca which offsets the high amounts of Ca adsorbed by these soils.

In considering the need for gypsum and lime for the production of peanuts, the soil physico-chemical properties, e.g., texture, CEC, pH and the initial levels of Ca and other cations in the soil should be taken into consideration. The above factors, including the rate of dissolution of gypsum and lime, and the equilibrium reactions between soil solution Ca and exchangeable cations will also influence the overall concentration of soil solution Ca.

Movement of Gypsum and Lime in Sandy Soils

The effectiveness of gypsum and lime in providing adequate Ca are dependent on their dissolution rates and on the amount of total Ca that resides in the zone where the peanut fruit develops (0-10 cm). Since lime application precedes gypsum top-dressing, the effect of lime on the solubility and subsequent movement of surface applied gypsum should be studied.

Chemical analysis of the Lakeland fine sand limed at four levels with $Ca(OH)_2$ indicated that the levels of exchangeable Ca and pH increased with rates of $Ca(OH)_2$ (Table 17). The observed decrease in levels of exchangeable Mg may be an error in the atomic absorption methodology probably because of the relatively very high Ca levels in solution which might have interferred with the sensitivity of the instrument.

The use of ^{45}Ca tagged gypsum made is possible to distinguish Ca initially contributed by the dissolution of gypsum. Water additions plotted against the concentration of total Ca in the effluent from the soil columns as affected bythe rates of lime and gypsum is presented in Figure 13. Values for the third levels of lime and gypsum, L_2 and G_2, respectively, were excluded to avoid crowding. In the absence of gypsum

Table 17. The pH and extractable cations as affected by $Ca(OH)_2$ in Lakeland Fine Sand.

$Ca(OH)_2$ Ca (me/100g)	pH	CEC*	Ca	Mg
0	5.73	2.83	1.81	0.81
1	6.73	3.41	2.49	0.71
2	7.05	3.87	3.06	0.61
4	8.03	5.58	4.86	0.52

*CEC was sum of cations extracted with N NH_4OAc (pH 7).

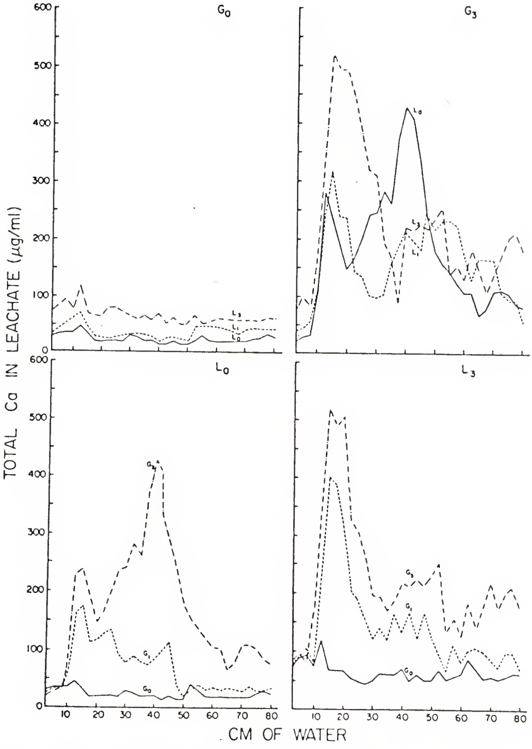


Figure 13. Total Ca concentration in the effluent of soil columns of Lakeland fs where L_0, L_1 and L_3 are 0, 200 and 800 ppm Ca as $Ca(OH)_2$ and G_0, G_1 and G_3 are 0, 200 and 800 ppm Ca as $^{45}CaSO_4 \cdot 2H_2O$, respectively.

the maximum concentration of total Ca in the effluent, which occurred after additions of 16 cm of water, ranged from 45 to 102 μg/ml at 0 and 800 ppm Ca as $Ca(OH)_2$, respectively. Although these concentrations were not significantly different at the four lime rates, there was an indication of increasing total Ca in the soil solution as the degree of Ca saturation increased (top left). The concentration of total Ca in the effluent increased significantly at the highest level of gypsum, 800 ppm Ca as $^{45}CaSO_4 \cdot 2H_2O$ (top right) and increased with increasing rates of gypsum in both unlimed (bottom left) and limed (bottom right) soil columns. The Ca concentration in the effluent reached a maximum after additions of 16 cm of water, except in the unlimed soil columns where the concentration peaked after 40 cm additions of water (top-right and bottom left). The concentrations of total Ca were not very different for the first 10 cm of water added but with further additions the data points diverge. This is because the effect of surface applied gypsum moving through the columns does not come into play until the original amount of water in the soil columns has been displaced by the gypsum solution. The reactions of isotopic exchange, cation exchange, and precipitation affect the downward movement of the Ca from gypsum. The amount of native Ca on the soil exchange sites will determine the extent of isotopic exchange between ^{45}Ca and ^{40}Ca. If the quantity of ^{45}Ca in solution exceeds that of ^{40}Ca in the soil exchange complex, then more ^{45}Ca will move down the columns than if the quantity of ^{40}Ca was greater. Similarly the exchange reactions between ^{45}Ca on one hand and the cations of Mg, K, and Na on the other hand will also affect the downward movement of ^{45}Ca. In the presence of CO_2 there is likelihood that some of the Ca is converted to insoluble $CaCO_3$ which may immobilized some of the Ca from gypsum.

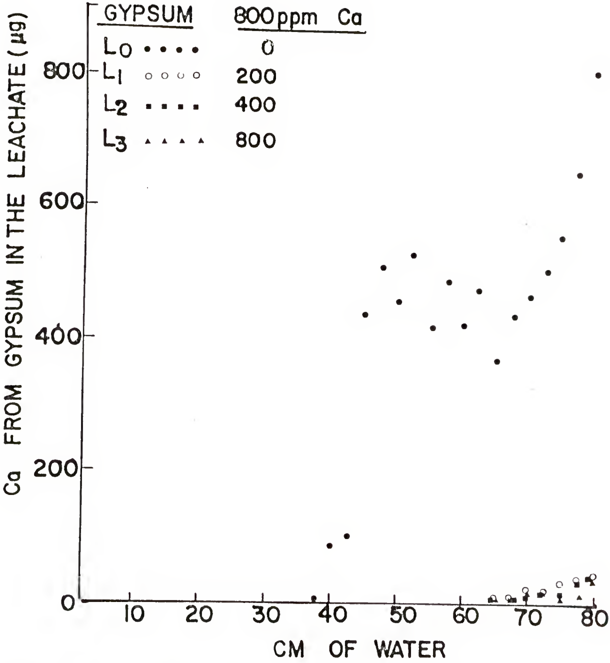


Figure 14. Ca from $^{45}CaSO_4 \cdot 2H_2O$ in the effluent from soil columns of Lakeland fs where L_0, L_1, L_2 and L_3 are 0, 200, 400, and 800 ppm Ca as $Ca(OH)_2$, respectively.

The peaking of the total Ca effluent concentration at 40 cm additions of water in unlimed soil columns that had 800 ppm Ca as $^{45}CaSO_4 \cdot H_2O$ coincides with the initial appearance of ^{45}Ca in the effluent from these columns only (Figure 14). The relatively low total Ca present in these columns allows the isotopic exchange to come to completion quickly with the remaining ^{45}Ca moving down the column. However, in limed soils the relatively high total Ca present means that much more ^{45}Ca is required to exchange with this amount of Ca. Consequently ^{45}Ca in the effluent from these columns appears much later (60 cm). After the native Ca, K, and Mg have been replaced, Ca from gypsum becomes the dominant cation in the effluent (Figure 14).

The concentration of total SO_4^{2-} in the effluent behaved similar to that of total Ca and started to increase rapidly after additions of 10 cm of water and reached a maximum at 16 cm of water added. After this point the concentration decreased gradually and leveled off after 60 cm (Figure 15). Since appreciable amounts of gypsum were still undissolved after 80 cm of water had been applied, the premature decrease in the SO_4^{2-} concentration after 16 cm may be a result of unequal dissolution of the different sized particles and also the fact that the undissolved gypsum was concentrated around the circumference of the columns away from the direct contact with the water. Further, the exclusion of the SO_4^{2-} ion from the exchange sites should be indicated by a wide plateau of maximum concentration from 16 cm and on if gypsum was dissolving at a uniform rate in the added water. In unlimed soil columns that had 800 ppm Ca from gypsum the SO_4^{2-} concentration in the effluent reached a second maximum at 45 cm of water, coinciding with the initial appearance of ^{45}Ca in the effluent from these columns (Figure 14). This

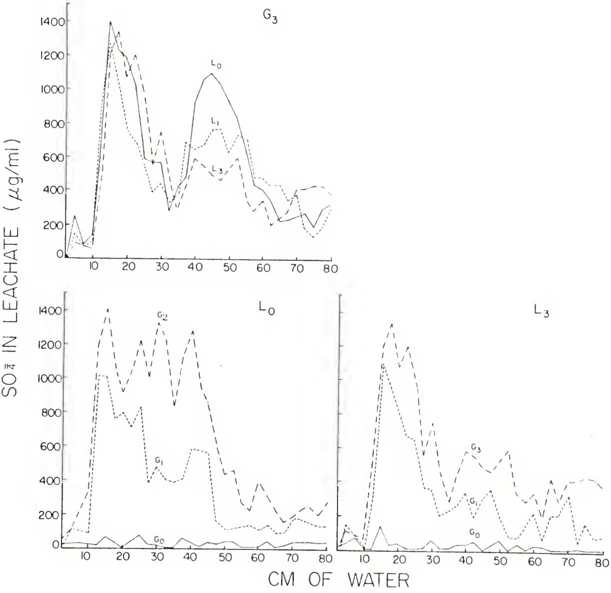


Figure 15. SO_4 concentration in effluent from soil columns of Lakeland fs where L_0, L_1 and L_3 are 0, 200 and 800 ppm Ca as $Ca(OH)_2$ and G_0, G_1, G_2 and G_3 are 0, 200, 400, and 800 ppm Ca as $^{45}CaSO_4 \cdot 2H_2O$, respectively.

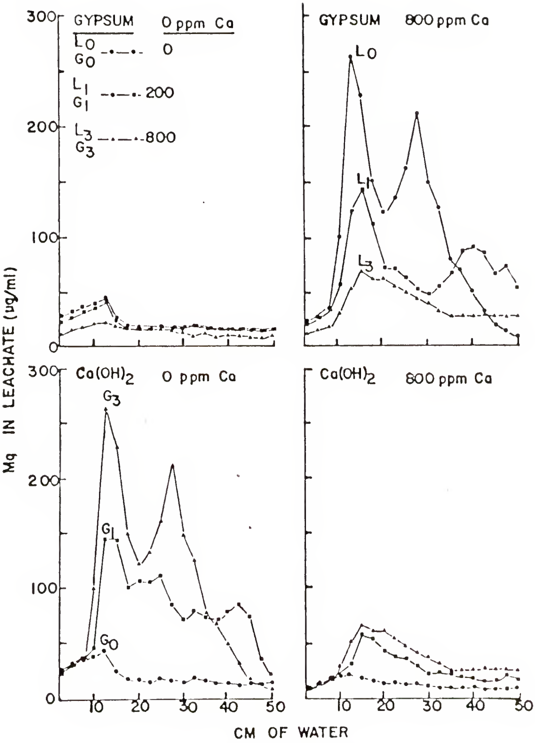


Figure 16. Mg concentration in effluent from soil columns of Lakeland fs where L_0, L_1 and L_3 are 0, 200 and 800 ppm Ca as $Ca(OH)_2$ and G_0, G_1 and G_3 are 0, 200 and 800 ppm Ca as $^{45}CaSO_4 \cdot 2H_2O$, respectively.

double peaking of SO_4 is attributed to problems at associated with non uniform contact of water with the gypsum resulting in an irregular rate of dissolution.

A plot of cm of water added against the concentration of Mg^{2+} in the leachates indicates that low levels of Mg^{2+} were found in the effluent from soil columns without gypsum, Figure 16 (top left). The introduction of gypsum (800 ppm Ca) resulted in a significant increase in the Mg^{2+} concentration with the maximum occurring in the unlimed columns (270 µg/ml) and the minimum (50 µg/ml) in columns with highest level of lime.

Gypsum had similar effects on the outflow of K^+ from the soil columns although the concentrations were much lower than those of total Ca^{2+} and Mg^{2+}. The highest level of gypsum significantly increased the K^+ concentration in the effluent, Figure 17 (top right) over columns without gypsum (top left), regardless of the lime levels (bottom). As with total Ca^{2+} and Mg^{2+}, the maximum K^+ concentration was reached after additions of 16 cm of water and decreased rapidly thereafter to near 0 µg/ml after additions of 50 cm of water.

With the exception of Ca^{2+} from gypsum, the concentration of native Ca^{2+}, Mg^{2+}, K^+, and SO_4^{2-} in the effluent from the soil columns reached a maximum after additions of 16 cm of water. The early appearance of Ca^{2+}, Mg^{2+}, and K^+ indicates that cations on the soil complex were displaced by gypsum according to the following reactions:

$$^{45}CaSO_4 \cdot 2H_2O + {}^{40}Ca - Soil \rightleftharpoons {}^{45}Ca - Soil + {}^{40}CaSO_4 + 2H_2O \quad [21]$$

and

$$Soil - (Mg^{2+}, 2K^+) + {}^{45}CaSO_4 \cdot 2H_2O + H_2O \rightleftharpoons Soil - {}^{45}Ca + Mg^{2+} + 2K^+ + SO_4^{2-} + 3H_2O \quad [22]$$

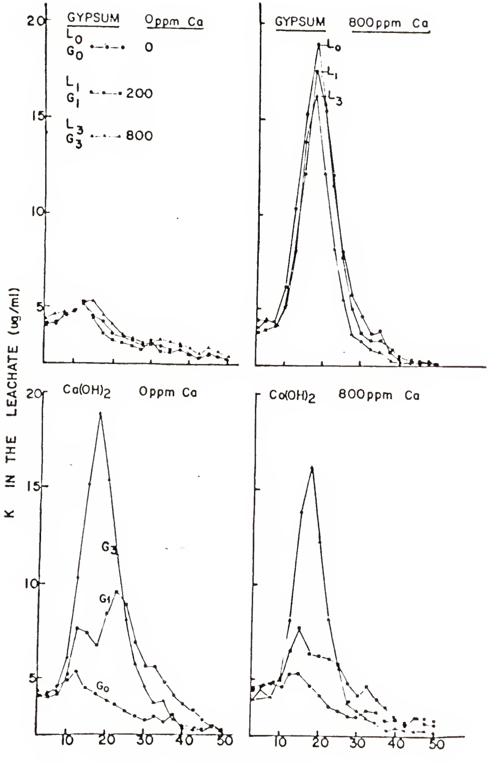


Figure 17. K concentration in the effluent from soil columns of Lakeland fs where L_0, L_1 and L_3 are 0, 200 and 800 ppm as $Ca(OH)_2$ and G_0, G_1 and G_3 are 0, 200 and 800 ppm Ca as $^{45}CaSO_4 \cdot 2H_2O$, respectively.

The isotopic equilibrium exchange between ^{40}Ca and ^{45}Ca plays the major role in the retention of ^{45}Ca. The increase in net negative charge sites brought about by liming, and the cation exchange between ^{45}Ca and Mg^{2+} and K^+ are minor. The SO_4^{2-} ion is supplied by the continued dissolution of gypsum and its resulting exclusion from the exchange sites of the soil makes it the predominant anion involved in maintaining electroneutrality when paired with the cations of Ca^{2+} and other bases.

The plot of EC against additions of cm of water, Figure 18, show that gypsum increased the EC of the effluent from the soil columns by increasing the concentrations of Ca^{2+}, Mg^{2+}, K^+, and SO_4^{2-}. The EC values follow trends similar to those of the effluent concentration Ca^{2+}, Mg^{2+}, K^+, and SO_4^{2-} and reached maximum values at 16 cm of water. It is only in the effluents from columns without gypsum that the maximum EC value is below 1.0 mmhos/cm, while effluents of gypsum treatments ranged from 2 to 3 mmhos/cm.

The pH of the effluent from soil columns without gypsum decreased with increasing additions of water at all levels of lime, Figure 19. In the absence of gypsum, the pH drop was greater in effluents from unlimed soil columns (top left). In unlimed soil columns which had the highest level of gypsum (800 ppm Ca), the pH dropped from the initial value of 7.8 to that of 6.8 after additions of 40 cm of water (top right and bottom left). Generally the pH increased with water additions up to 5 cm, thereafter it gradually decreased, with the decrease being dependent on the levels of lime, until 40 cm of water had been added. After this point, the pH starts to increase.

The movement of ^{40}Ca resulting from the dissolution of surface applied gypsum is shown in Table 18. The isotopic exchange between

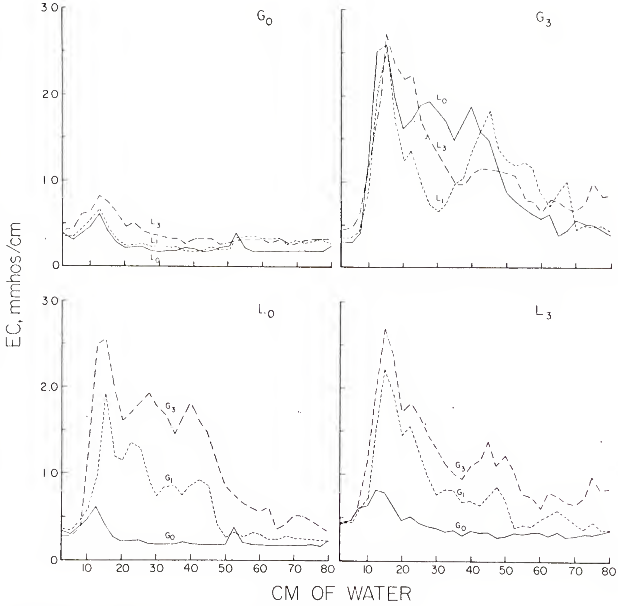


Figure 18. Electrical conductivity (EC) of effluent from soil columns of Lakeland where L_0, L_1, L_3 are 0, 200 and 800 ppm Ca as $Ca(OH)_2$ and G_0, G_1 and G_3 are 0, 200 and 800 ppm Ca as $^{45}CaSO_4 \cdot 2H_2O$, respectively.

^{45}Ca and ^{40}Ca made the calculation of Ca from gypsum retained in the soil column difficult. In unlimed soil columns the total ^{40}Ca retained in the soil tended to increase with depth but decreased with levels of gypsum. In columns that had no gypsum there was little change in amounts with increasing depth. This coincides with low Ca concentration in the effluents from these columns depicted in Figure 13 above. However, in limed soil columns the amounts of total ^{40}Ca increased with depth at all levels of gypsum as evidenced by the increase in the total Ca concentration from these columns in Figure 13. As would be expected, the amounts of total ^{40}Ca retained in the 0-10 cm segment of the soil columns and in the whole column (0-25 cm) were greatest in those that received the highest level of lime 800 ppm Ca as $Ca(OH)_2$. The highest amounts of total ^{40}Ca in the lower segments of the columns represent increasing quantities of dissolving gypsum moving down the soil columns. Further, the data does show that lime reduced the rate of dissolution of gypsum, likely because of the common ion effect. In unlimed columns (L_0) 36, 52, and 62% of the applied gypsum at G_1, G_2, and G_3 respectively was not dissolved after 80 cm of water had been added. However in columns that had 400 ppm Ca of $Ca(OH)_2$ (L_2) 39, 61, and 77% of the applied gypsum at G_1, G_2, and G_3, respectively remained undissolved after 80 cm additions of water.

The percent of the total ^{45}Ca tagged Ca retained in each segment of the soil column, excluding that found in the effluent and the undissolved part left after leaching with 80 cm of water is presented in Figure 20 to 22. The percent of ^{45}Ca residing in the 0-5 cm segment of the column increased with increasing levels of lime at low level of gypsum (200 ppm Ca.as $^{45}CaSO_4 \cdot 2H_2O$), Figure 20. However, the total

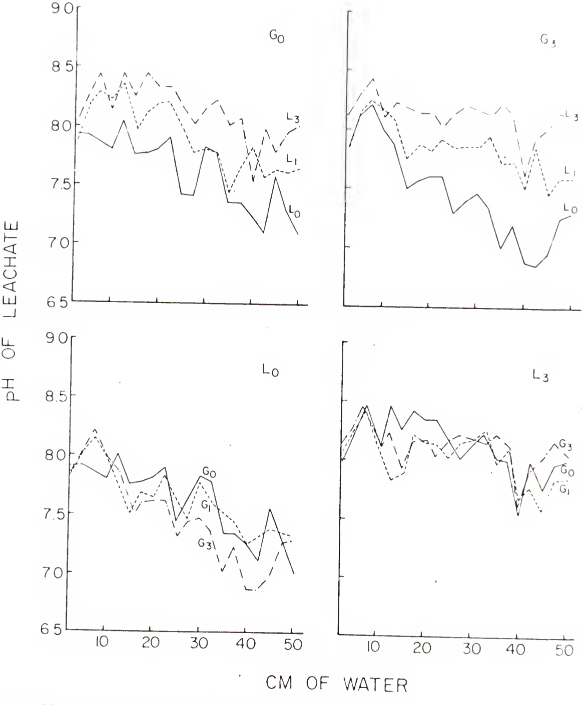


Figure 19. pH of effluent from soil columns of Lakeland fs where 0, 200 and 800 ppm Ca as $Ca(OH)_2$ G_0, G_1 and G_3 are 0, 200 and 800 ppm Ca as $^{45}CaSO_4 \cdot 2H_2O$, respectively.

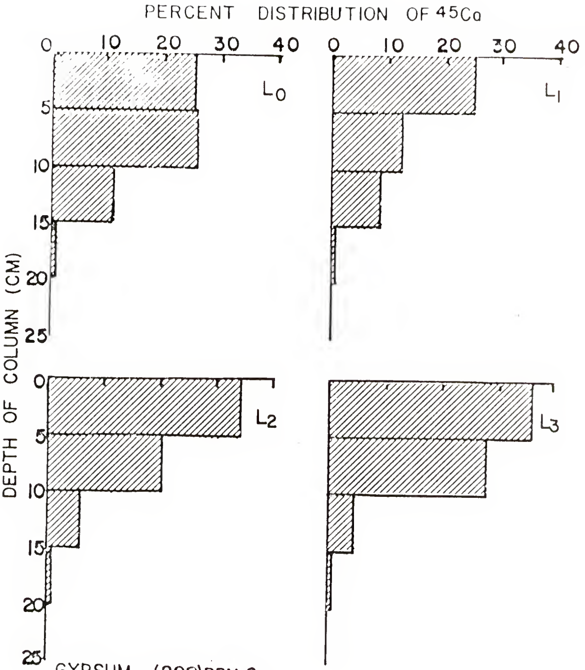
Table 18. Distribution of Ca in the Soil Columns of Lakeland fs Extracted with N NH_4OAc pH 7.*

Soil Segment	Lime Levels															
	L_0				L_1				L_2				L_3			
	Gypsum Levels															
	G_0	G_1	G_2	G_3	G_0	G_1	G_2	G_3	G_0	G_1	G_2	G_3	G_0	G_1	G_2	G_3
	^{40}Ca in soil columns (mg)															
0- 5	36.4	30.2	30.8	22.2	51.8	51.9	37.6	29.1	61.9	47.2	44.2	44.7	65.6	62.2	41.4	51.5
5-10	45.4	18.6	12.1	6.8	58.4	51.0	30.7	12.4	72.4	47.4	38.4	40.5	86.1	47.9	54.1	58.1
10-15	43.8	40.6	27.7	4.2	56.8	40.0	51.9	29.3	71.2	65.6	58.7	54.8	82.7	100.7	96.7	50.9
15-20	43.4	55.4	43.1	21.1	55.5	59.5	61.4	54.6	72.4	74.8	68.0	67.3	91.2	116.8	105.3	87.3
20-25	39.1	45.6	52.2	37.4	50.8	52.5	72.2	59.0	63.4	68.3	63.5	69.6	79.3	98.7	99.1	88.8

*L_0, L_1, L_2 and L_3 represent 0, 200, 400 and 800 ppm Ca as $Ca(OH)_2$, respectively; G_0, G_1, G_2 and G_3 represent 0, 200, 400 and 800 ppm Ca as $^{45}CaSO_4 \cdot 2H_2O$, respectively.

amount retained by the entire 25 cm column, as a percent of the total applied was 64, 45, 61, and 67% at 0, 200, 400, and 800 ppm as $Ca(OH)_2$. No ^{45}Ca was detected in the 20-25 cm segment of these columns. At the highest level of gypsum (800 ppm Ca), the percent of the total Ca from gypsum residing in the 20-25 cm segment increased significantly only in unlimed soil columns (L_0) Figure 21. This coincides with the appearance of ^{45}Ca activity in these columns (Figure 14). The histograms are deceiving in that they indicate a decrease in the percent distribution of Ca from gypsum with increasqng rates of gypsum. Actually the percent retained increases with levels of gypsum and lime.

The effect of lime in the distribution of Ca from gypsum is shown in Figure 22. Actual percent distribution in the 0-10 cm segment increases with rates of lime applied. The percent of Ca from gypsum residing in the 0-5 cm segment increased with rates of lime applied probably because of the isotopic exchange between ^{45}Ca and ^{40}Ca. The increase in the downward movement of surface applied Ca with increasing rates of gypsum and is a result of the non-linearity of the Ca adsorption isotherm of the Lakeland fine sand soil (Figure 23). With increasing soil solution Ca, less Ca will be adsorbed by the soil complex consequently more will move downward. Similarly as soon as most of the Mg^{2+} and K^+ on the soil exchange complex has been replaced by the Ca from gypsum, the downward movement of Ca is increased. The increase in net negative charge with rates of lime application (Figure 24) also contributes to the movement of Ca from gypsum in the soil columns. There is an equilibrium between Ca on the exchange sites and Ca in the soil solution. As soon as this equilibrium has been reached further Ca additions will result in most of it being leached through the soil



GYPSUM	(200)PPM Ca
L_0	0
L_1	200
L_2	400
L_3	800

Figure 20. Percent distribution of ^{45}Ca in soil columns of Lakeland fs at four levels of lime and low level of gypsum.

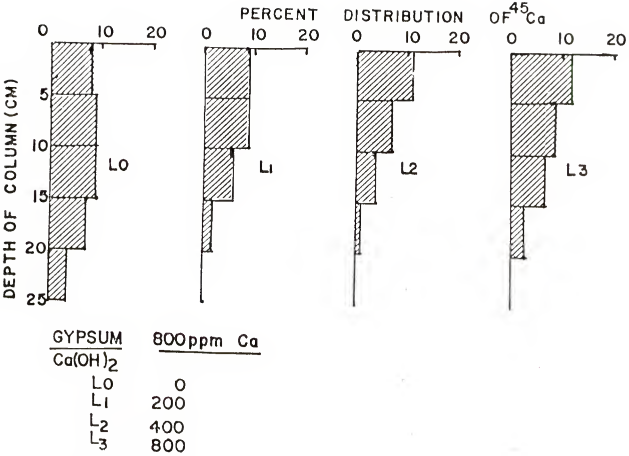


Figure 21. Percent distribution of ^{45}Ca in soil columns of Lakeland fs at four levels of lime and high level of gypsum.

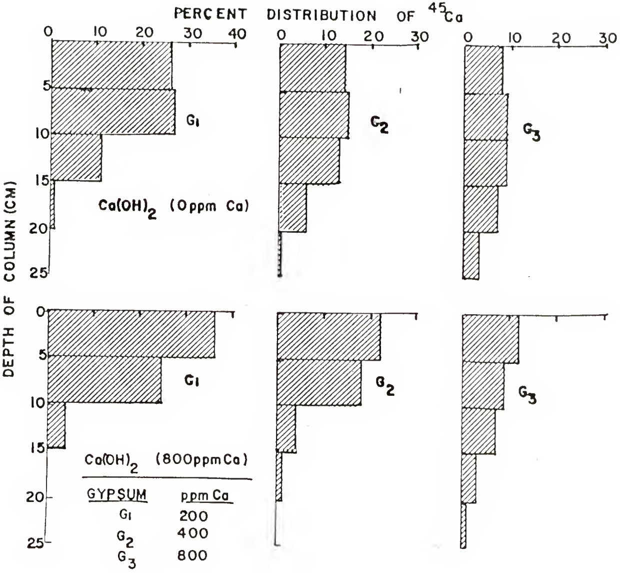


Figure 22. Percent distribution of ^{45}Ca in soil columns of Lakeland fs at three levels of gypsum and two levels of lime.

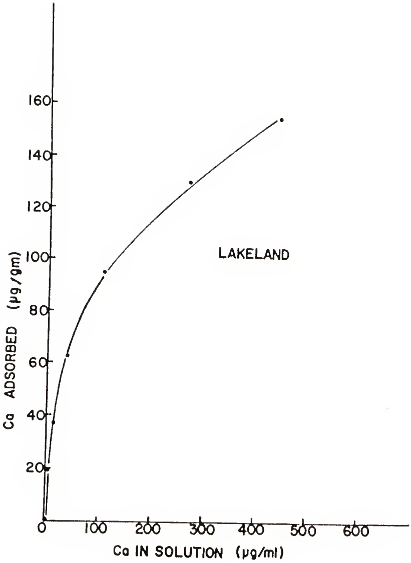


Figure 23. Ca ($CaSO_4 \cdot 2H_2O$) adsorption isotherm of Ap horizon of Lakeland fine sand soil.

columns. The effective concentration of ^{40}Ca depends on the ease of contact with ^{45}Ca in solution. Hence, solid phase Ca in inaccessible clay interlayers or $CaCO_3$ particles will be very slow in reaching equilibrium with the Ca from gypsum.

The application of lime and gypsum to peanuts will be beneficial to the extent that the concentration of Ca in the soil solution of the fruiting zone will be high enough for normal fruit development. If the supply of Ca is too low or the bonding energy of the exchange complex to high to provide adequate Ca in the soil solution, the Ca level may be increased by the application of gypsum to the soil surface.

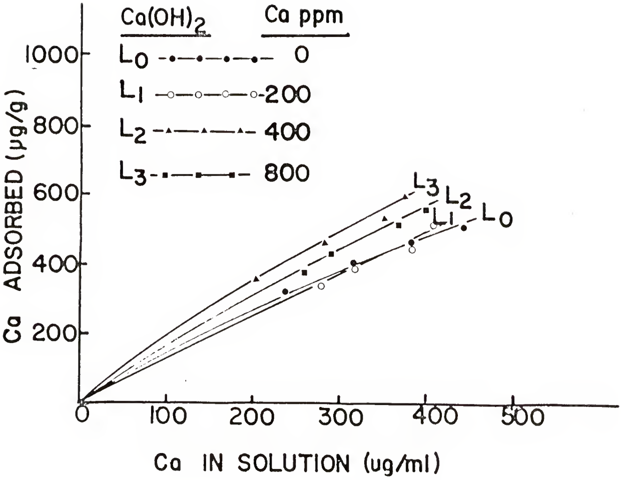


Figure 24. Ca (CaSO$_4$·2H$_2$O) adsorption isotherm of Lakeland fs limed at four levels.

Greenhouse Experiment (1974)

This experiment was carried out to determine the effect of inoculum, lime as $Ca(OH)_2$, gypsum and micronutrients (Cu, Mn and Zn) on the vegetative growth of Florunner peanuts.

The summary of the analysis of variance of yield of tops, soil and plant-tissue chemical analyses are presented in Tables 19 and 21. Calcium hydroxide had a significant effect not only on the yield of tops but also on the pH and amounts of Mg, K, Cu and Zn in the foliage (Table 19). The yield of tops increased, albeit not significantly, to applications of 1000 ppm of $Ca(OH)_2$ thereafter yield declined significantly at 2000 ppm $Ca(OH)_2$ as it did when 50 ppm of gypsum were added (Table 20).

The adverse effects of high rates of $Ca(OH)_2$, Mn, and gypsum on yield of tops may be attributed to the nutritional imbalance effect brought about by preponderant amounts of Ca inducing loss of both K and Mg from the soil and thus reducing their uptake by the plant. This is evidenced by the increase in Ca and the decline in K and Mg in the soil with increasing rates of $Ca(OH)_2$ (Table 20). The differences between Ca and Mg values extracted with NH_4OAc at pH 4.8 and double acid could be due to the ability of the latter to extract Mg converted to $Mg(OH)_2$ by high pH (Table 22) and an error in the analysis of these nutrients.

Analysis of variance of the plant tissue data (Table 23) indicate that $Ca(OH)_2$ increased the uptake of Ca but reduced that of Mn and Zn (Table 24).

Table 19. Analysis of Variance of Yield of Tops of Florunner Peanuts and Soil Data of Lakeland fs in the Greenhouse Experiment.

Source	df	Yield	pH	N NH4OAc (pH 4.8) K	N NH4OAc (pH 4.8) Ca	N NH4OAc (pH 4.8) Mg
		---mean square---				
Blocks	2	2.5	0.00	504.3	8775	744.4**
Treatments	19	3.8**	0.91**	1406.9	179802**	209.4**
Lime (L) Linear	1	1.5	14.00**	7344.1**	2815364**	2002.2**
Quad.	1	3.8*	0.5 *	3030.9	125	21.5
Cubic	1	1.4	0.3	509.7	133404*	117.8
Quartic	1	6.4*	0.2	2191.5	37361	5.3
Mn - Linear	1	7.4**	0.1	450.5	4	4.8
Quad.	1	0.6	0.00	256.0	67927	38.8
L x Mn	8	2.6*	0.1	578.9	38588	26.5
L, Mn vs others	1	10.5**	1.3 **	661.2	81	1548.8**
Other interactions	4	4.4**	0.1	1913.8	13316	6.8
Error	38	0.9	0.1	840.0	24343	59.2

*Significant at the 5% level

**Significant at the 1% level

Table 20. Yield of Tops of Florunner Peanuts and Soil Data Showing Response to Lime and Mn on Lakeland fs in the Greenhouse Experiment.

Treatment No.	Material*	Yield	pH	N NH_4OAc (pH 4.8)		
				K	Ca	Mg
	$Ca(OH)_2$(ppm)	(g/pot)		ppm		
1	0	6.34	6.8	103.0	266.4	34.4
2	250	7.07	7.4	67.4	523.3	27.2
3	500	6.07	7.5	76.6	534.4	25.0
4	1000	7.23	7.9	57.6	628.9	23.1
5	2000	5.88	8.5	56.4	1057.8	13.0
	Mn(ppm)					
6	0	5.79	7.7	66.7	641.5	25.8
7	5	6.84	7.6	74.2	549.3	23.4
8	20	5.92	7.5	75.7	615.8	24.4
	Treat. combinations					
9	3+8+I	5.93	7.4	67.3	617.3	26.0
10	4+8+I	7.73	7.8	51.7	627.3	23.3
11	3+8	5.33	7.8	74.7	503.3	11.3
12	4+8	5.07	8.0	111.7	637.7	11.3
13	4+8+Cu	6.97	8.0	53.7	634.0	12.7
14	4+8+G	3.83	7.8	59.8	576.0	14.3
15	4+8+B	6.33	8.1	100.0	673.3	14.3

*Mn was $MnCl_2 \cdot 4H_2O$; I was inoculated; Cu at 5 ppm as $CuCl_2 \cdot 2H_2O$; G was 50 ppm $CaSO_4 \cdot 2H_2O$; B at 0.5 ppm as $NaBO_3 \cdot 4H_2O$.

Table 21. Analysis of Variance of Soil Data of Lakeland fs Extracted with Double acid in the Greenhouse Experiment.

Source	df	Double Acid (.0.05N NCl + .025N H_2SO_4					
		K	Ca	Mg	Mn	Cu†	Zn
		---mean square---					
Blocks	2	2691.7*	14454	644.0	18.6**	5.4**	2.1
Treatments	19	1350.0*	240991**	542.3	1.6	0.9	1.0
Lime (L) Linear	1	9849.1**	3810799**	3584.7	0.0	4.9*	6.4**
Quad.	1	2600.8*	18699	721.7	1.3	1.5	0.6
Cubic	1	22.6	1578	7.2	7.3*	0.6	1.9
Quartic	1	681.9	28102	547.6	4.3	5.8*	1.0
Mn - Linear	1	1102.0	2944	315.9	3.6	0.4	0.9
Quad.	1	478.5	124709	431.0	2.4	0.0	1.7
L x Mn	8	755.6	44660	420.5	1.1	0.2	0.6
L, Mn vs others	1	875.6	44793	108.9	1.2	1.8	1.6
Other interactions	4	998.6	47480	305.7	0.2	0.0	0.1
Error	38	563.2	82758	1185.6	1.4	0.9	0.8

†Mean squares must be multiplied by 10^{-2}

*Significant at the 5% level

**Significant at the 1% level

Table 22. Means of Soil Analysis Data of Lakeland fs in the Greenhouse Experiment.

Treatment No.	Material*	Double Acid (0.05N HCl + 0.025N H_2SO_4) K	Ca	Mg	Mn	Cu	Zn
	$Ca(OH)_2$(ppm)	ppm					
1	0	104.9	617.4	83.3	5.5	0.43	2.0
2	250	81.2	738.8	99.3	4.3	0.37	2.1
3	500	81.3	748.0	95.3	5.2	0.50	2.6
4	1000	60.3	997.8	109.7	5.8	0.50	2.1
5	2000	57.8	1439.1	121.1	4.9	0.50	3.2
	Mn(ppm)						
6	0	68.9	969.8	99.4	5.1	0.45	2.3
7	5	79.6	839.9	105.2	4.7	0.45	2.7
8	20	82.8	915.0	95.3	5.6	0.47	2.1
	Treat. combinations						
9	3+8+I	73.7	741.0	95.3	6.3	0.50	2.2
10	4+8+I	55.3	965.0	100.7	6.9	0.50	2.4
11	3+8	96.7	767.7	102.0	4.4	0.50	2.2
12	4+8	104.3	1091.7	111.3	5.0	0.50	1.9
13	4+8+Cu	64.3	947.7	86.7	5.3	0.50	2.1
14	4+8+G	71.0	1053.7	111.3	4.7	0.50	2.3
15	4+8+B	103.3	991.7	104.0	4.9	0.50	1.7

*Mn was $MnCl_2 \cdot 4H_2O$; I was inoculated; Cu was 5 ppm as $CuCl_2 \cdot 2H_2O$; G was 50 ppm $CaSO_4 \cdot 2H_2O$; B was 0.5 ppm as $NaBO_3 \cdot 4H_2O$.

Table 23. Analysis of Variance of Plant Tissue Data of Peanuts Grown on Lakeland fs in Greenhouse Experiment.

Source	df	Ca	Mg†	Mn	Cu	Zn	K
		mean square					
Blocks	2	0.00	0.22	5612.60	0.3407	7.62	0.10
Treatments	18	0.12*	1.48**	52010.58**	5.8736**	66.65**	0.26
Lime (L) Linear	1	0.44**	22.50**	143840.04**	2.8801	518.40**	0.76*
Quad.	1	0.02	0.066	23275.99	0.8757	354.68**	0.18
Cubic	1	0.01	0.85*	22016.82	0.0306	87.38	0.60
Quartric	1	0.06	1.90**	642.12	0.0394	26.07	0.22
Mn - Linear	1	0.03	0.25	296455.88**	0.3419	32.83	0.01
Quad.	1	0.26*	0.06	13305.86	1.2186	16.41	0.09
L x Mn	8	0.04	0.13	30327.14**	0.4083	12.40	0.16
L, Mn vs others	1	0.58**	0.67	169280.00**	37.0828**	52.27	0.06
Other interactions	4	0.07	0.07	19191.77	16.4660**	19.77	0.44
Error	38	0.05	0.18	9697.56	0.7065	27.19	0.18

†Mean squares must be multiplied by 10^{-2}

*Significant at the 5% level

**Significant at the 1% level

The levels of Mn, increased with rates of Mn application to a maximum of 237 ppm. The amounts of K in the tops, like the yield of tops, was significantly decreased by gypsum.

The lime x Mn interaction showed significant quartic and cubic regression of yield of tops at 5 and 20 ppm of Mn, respectively (Table 25). At lower levels of lime, high rates of Mn reduced yield, probably because of toxic levels of Mn in the plant. Significant quadratic regression of plant tissue Mn was obtained only at the highest level of Mn (20 ppm); otherwise, levels of Mn decreased with increasing levels of lime. This is largely a pH effect which reduced the solubility of Mn.

The failure of inoculum, Cu, and B to affect the yield of tops indicates that soil N, Cu and B levels were not limiting factors for the vegetative growth of Florunner peanuts. Possibly some of the uninoculated plants had been contaminated with inoculum, and Cu and B were adequately supplied by previous fertilizer applications.

This results indicate the detrimental effect of high rates of pH and Mn on the vegetative growth of Florunner peanuts. This effect induced by the excessive application of lime and gypsum. Extrapolation of these results to field conditions could be erroneous because of confinment of plants in pots as compared to the large volume of soil in contact with the plant in the field.

Table 24. Plant Tissue Data Showing Response to Lime and Mn on Lakeland fs in the Greenhouse Experiment.

Treatment No.	Material*	K	Ca	Mg	Mn	Cu	Zn
	$Ca(OH)_2$(ppm)	------------	%	------------	------------	ppm	------------
1	0	2.04	1.00	0.31	229.1	3.50	24.1
2	250	2.24	1.01	0.29	147.1	3.37	18.6
3	500	2.58	1.18	0.19	92.3	3.08	12.4
4	1000	2.31	1.16	0.20	96.6	2.79	12.8
5	2000	2.54	1.29	0.10	35.6	2.79	12.2
	Mn(ppm)						
6	0	2.31	1.07	0.21	68.1	3.19	15.8
7	5	2.41	1.24	0.22	64.9	2.85	14.9
8	20	2.31	1.07	0.23	237.4	3.28	17.4
	Treat. combinations						
9	3+8+I*	2.50	1.10	0.20	150.0	2.93	13.0
10	4+8+I	2.17	1.07	0.23	146.7	3.37	15.3
11	3+8	2.63	1.13	0.20	355.7	3.77	17.3
12	4+8	2.57	1.43	0.20	292.0	3.77	15.0
13	4+8+Cu	2.43	1.27	0.20	221.3	9.10	14.3
14	4+8+G	1.80	1.43	0.20	179.0	3.80	11.3
15	4+8+B	1.93	1.50	0.17	166.0	4.17	11.3

*Mn was $MnCl_2 \cdot 4H_2O$; I was inoculated; Cu was 5 ppm as $CuCl_2 \cdot 2H_2O$; G was 50 ppm $CaSO_4 \cdot 2H_2O$; B was 0.5 ppm as $NaBO_3 \cdot 4H_2O$.

Table 25. Yield of Tops and Plant Tissue Mn as a Response to Lime x Mn interaction in Greenhouse Experiment.

Mn (ppm)	Lime (ppm)					Relationship
	0	250	500	1000	2000	
	-----------Yield (g/pot)-----------					
0	6.80	7.33	7.00	6.90	5.93	Nonsignificant
5	6.73	8.63	5.27	7.07	6.50	Quartic
20	5.50	5.23	5.93	7.73	5.20	Cubic
	Mn (ppm)					
0	39.0	28.7	84.7	108.3	28.3	Nonsignificant
5	168.0	52.0	41.3	34.7	28.7	Nonsignificant
20	480.0	360.7	150.0	146.7	49.7	$462.54 - 134.57L + 10.50L^2$

Field Experiment I (1974)

This field experiment was initiated to test findings in the greenhouse experiment discussed above and involved treatment combinations shown in Table 3.

The analyses of variance of peanut yields of unshelled nuts (pods) virginia pods, ELK, vines (tops) soil analyses and plant tissue analyses data are presented in Table 26. None of the 21 treatments had any significant effects on yield of pods, tops, or on the yield of Virginia pods and extra large kernels (ELK) Table 27. However, the highest yield of pods (6139 kg/ha) was obtained with treatment involving inoculum, 20, 50 and 400 kg/ha of Mn, SCK, and gypsum, respectively and while treatment 21, control, had the lowest yield (4228 kg/ha). The yield of tops, unlike the yield of pods, were lowest (2171 kg/ha) and highest (4960 kg/ha) in treatments 21 control and 5, respectively. The latter consisted of inoculum, 20, 50, 50, and 400 kg/ha of Mn, N, SCK, and gypsum, respectively.

The lack of yield and quality response of Florunner peanuts to inoculum, gypsum, K, and Mn application is probably because soil had adequate amounts inoculum and nutrients. The amounts of Ca, K, P, N, and micronutrients supplied by the base application of 2200, 300, 200, and 30 kg/ha of lime, 21-7-14 fertilizer, NH_4NO_3, and micronutrient frit, respectively, were adequate for the observed yield of peanuts. This point is born out by the lack of any significant difference in amounts of soil nutrients at harvest. Among treatments 7, 8, 9, 10, and 11, which had 0, 100, 200, 400, and 800 kg/ha gypsum, respectively, exchangeable Ca at harvest was 238, 100, 173, 243, and 200 ppm, respectively, while the check treatment had 153 ppm Ca. Similarly, there were no differences

Table 26. Analysis of Variance of Yield of Tops, Soil and Plant Tissue Data of Field Experiment I Conducted in Lakeland fs.

Response	Source of Variation		
	Treatment	Blocks	Error
	--------------mean square-------------		
Yield			
Pods	872786	66873	1032758
Tops	644067	13814788**	1412184
$\underline{N}$ NH_4OAc (pH 7)			
pH	0.06623	.1.09**	0.08
Ca	7924.40	7410.76	10878.16
Mg	16.23	2.6806	11.89
K	13.45	110.9306**	12.79
Double Acid			
Ca	8145.47	6151.35	6678.78
Mg	930.47	157.79	784.53
K	4.16	16.6667*	4.30
Mn	108.68	27.1250	189.24
Cu	0.63	0.1667	0.59
Plant Data			
Ca	5380541	92655937**	3850059
Mg	767925	4530217**	658079
K	8605226	86698290**	7925156
Mn	72164**	3445	20107
Cu	732.05	41058.32**	629.00
Zn	51.13*	47.16	23.35
df	20	2	40
Virginia Pods	18327.74	18327.74	9124.80
Extra-Large Kernels (ELK)	4907.58	12033.33	4263.55
df	20	1	20

*Significant at the 5% level
**Significant at the 1% level

Table 27. Yield and Quality Florunner Peanuts and Soil Analysis Data of Lakeland fs in Field Experiment I.

Treatment No.*	Yield (kg/ha)				pH	1N NH_4OAc(pH 7)			(0.05N HCl+0.025N H_3SO_4)			Double Acid	
	Pods	Virginia Pods	ELK	Tops		Ca	Mg	K	Ca	Mg	K	Mn	Cu
						ppm							
1	5936	387.0	527.0	4228	5.80	228	15.33	12.33	138.7	50.00	12.33	22.67	3.67
2	4310	248.5	495.5	3822	5.63	155	12.33	10.33	156.7	50.00	12.00	24.33	3.00
3	4919	392.5	587.5	4196	5.60	175	11.33	10.67	115.7	32.00	10.67	32.33	2.67
4	4635	423.5	582.5	3936	5.83	286	17.33	12.67	223.0	55.33	12.33	42.33	3.00
5	5123	322.4	528.0	4960	5.73	275	14.33	12.33	215.3	62.00	12.17	32.33	4.00
6	4716	419.5	585.5	4066	5.73	215	13.00	13.00	128.7	34.00	11.67	23.00	3.67
7	5123	513.0	621.5	4228	5.80	238	17.00	8.67	227.7	74.00	11.33	35.33	3.00
8	4679	305.5	602.5	4066	5.37	100	9.67	8.67	84.3	21.00	9.83	19.67	3.33
9	4554	285.0	555.0	3903	5.60	173	11.00	9.67	169.0	47.00	10.50	23.67	4.00
10	6139	355.0	596.0	4391	5.60	243	14.00	9.00	202.7	67.00	11.17	36.33	3.67
11	5424	280.5	541.0	4554	5.87	200	14.33	10.67	146.0	38.00	11.17	31.00	4.33
12	4757	253.0	590.5	3578	5.80	255	18.33	7.00	169.7	58.00	9.50	32.33	4.00
13	4920	243.5	529.0	3740	5.77	271	15.67	11.33	296.0	88.33	10.50	34.33	4.00
14	5164	236.5	514.0	4879	5.93	301	15.67	14.00	276.0	67.00	12.83	31.67	4.00
15	4391	311.5	499.5	3659	5.80	233	16.67	10.67	173.0	50.00	10.50	34.33	3.00
16	4594	384.5	626.5	3659	5.63	233	17.33	12.67	158.0	45.00	11.17	30.67	3.67
17	5041	296.0	507.0	3659	5.93	226	15.67	12.33	228.3	75.00	11.33	30.67	4.00
18	4270	117.0	443.0	4391	5.80	218	14.00	5.00	188.7	38.33	8.50	30.33	3.00
19	5326	219.5	469.5	4797	4.87	286	18.00	11.67	209.7	61.00	12.00	38.00	3.33
20	6098	305.5	537.5	4391	5.63	153	16.00	9.67	142.3	70.67	10.67	33.67	3.00
21	4228	134.0	487.5	3171	5.40	153	14.67	9.00	191.0	51.67	9.50	19.67	3.33

*See Table 3 for treatment details.

among treatments in the levels of Mg, K, Mn, and Cu in the soil at harvest. Consequently it can be condluded that lime at the rate of 2200 kg/ha provided adequate Ca for the maximum yield and quality of peanuts.

Gypsum and Mn did not have the same effect in the field as they did in the greenhouse, that is the reduction in yield of tops at the high rates. This indicates that field pH levels much lower to produce the adverse effect encountered in the greenhouse experiment. The lack of significant differences in pH values among the treatments is further evidence of the ability of lime to supply adequate Ca over the growing period. Among gypsum treatments (7,8,9,10, and 11), there was a trend towards lower K levels in the soil at harvest, probably as a result of K being exchanged for Ca (51) and leached (29). There was good agreement between the values of Ca and K extracted with $\underline{N}$ NH_4OAc at pH 7 and that by double acid.

In the plant tissue data, only Mn and Zn varied significantly among treatments (Table 28). Levels of Mn increased with rates of applied Mn. Application of 0, 10, 20, and 40 kg/ha Mn resulted in the levels of 86, 166, 316, and 475 ppm Mn in the plant tissue. In fact in all Mn treatments Mn values were above 100 ppm. However, Mn levels were not associated with any significant increase or decrease in the yield of pods, tops, Virginia pods and extra large kernals (77). Treatments receiving high amounts of Mn had the highest levels of this nutrient in the plant tissue (Table 28). There was no good explanation for the variance in plant tissue Zn among the treatments.

At harvest the levels of extractable Ca, Mg, K, and Mn in the unfertilized plot were 172, 38, 9, and 94 ppm respectively with a pH of

Table 28. Means of Plant Analysis Data of Florunner Peanuts in Field Experiment I (1974).

Treatment No.*	Plant Data (0.05N HCl)					
	Ca	Mg	K	Mn	Cu	Zn
	%			ppm		
1	1.80	0.32	1.40	86e[†]	42	16e
2	1.77	0.33	1.69	166de	51	23bcde
3	1.75	0.27	1.66	316bcd	36	32abc
4	1.92	0.36	1.63	475be	38	26abcd
5	1.76	0.33	1.77	313bcde	42	24bcde
6	1.85	0.32	1.66	445bcd	49	25abcde
7	1.86	0.35	1.66	222bcde	48	25bcde
8	1.70	0.32	1.80	492b	44	23cde
9	1.78	0.29	1.87	805a	52	34a
10	1.75	0.33	1.50	228bcde	43	22de
11	1.65	0.31	1.73	223bcde	49	21de
12	1.86	0.37	1.47	284bcde	61	21de
13	1.79	0.43	1.67	212bcde	39	25abcde
14	1.76	0.27	1.99	184cde	40	24bcde
15	1.79	0.36	1.66	216bcde	52	22cde
16	1.65	0.28	1.38	450bc	51	21de
17	1.74	0.31	1.72	163de	44	24bcde
18	2.10	0.35	1.35	407bcd	85	27abcd
19	2.13	0.43	1.42	308bcde	87	24bcde
20	2.07	0.46	1.31	287bcde	70	24bcde
21	1.70	0.35	1.57	94e	93	29abcd

*See Table 3 for treatment details.

[†] Means separation within columns by Duncan's multiple range test, 5% level.

5.4. The infrequent response to gypsum and other fertilizers in the experiment can be attributed, largely, to the nutrients supplied by the base lime and fertilizer material application. This is further evidence that lime in this acid sandy soil does supply enough Ca for the production of maximum yield and quality of peanuts, to make gypsum top-dressing unnecessary.

Field Experiment II (1974)

In June 1974, a second field experiment was initiated on the Agronomy farm of the University of Florida to study the effect of gypsum on the yield and quality of Early Bunch (UF 70115), Florigiant, and Florunner peanuts.

The yields of pods, Virginia pods and parameters used to measure peanut fruit quality are presented in Table 29. None of the factors measured was significantly affected by rates of gypsum. At rates of 0, 800, and 1600 kg/ha gypsum yield and shelling % was highest in the Florunner variety (4456, 4810, and 4329 kg/ha and 81.2%, 81.1%, and 80.7%, respectively). The percent of Virginia pods was highest in the Florigiant variety where it varied from 80.2 to 81.7 percent and lowest in the Florunner variety, ranging from 14.4 to 17.2%. Gypsum reduced the % VD and % CD in the Early Bunch variety and increased them in the Florigiant variety.

The lack of significant response for the yield and quality of the three varieties of peanuts to rates of gypsum is again the reflection on the inability of gypsum to increase yield and quality in levels of Ca. Preplant soil anslysis of the Arredondo soil indicated a pH of 6.2

Table 29. Yield and Quality of Three Varieties of Peanuts as a Response to Gypsum on Arredondo fs in Field Experiment II.*

Variety	Gypsum	Yield Pods	Va. pods.	Other kernels	Sound splits	Visual damage	Concealed damage	Extra large kernels	Sound mature kernels	Shelling	WT 100 SMK.
	kg/ha		%								gm
Early Bunch	0	3467	76.6	0.9	3.6	1.1	0.4	46.3	69.2	75.2	94.9
	800	3612	68.4	1.4	2.2	1.4	0	41.4	70.1	75.1	88.8
	1600	3757	68.6	1.1	2.3	.6	0.1	45.0	70.7	74.8	92.4
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Florigiant	0	4138	81.2	2.2	3.3	0.4	0.1	45.2	67.7	73.7	99.7
	800	4020	81.7	2.0	3.3	1.0	0.1	47.0	67.4	73.8	102.1
	1600	4274	80.2	1.9	4.2	0.6	0.4	45.2	66.4	73.3	99.3
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Florunner	0	4456	17.2	2.2	3.9	1.3	0.1	44.1	73.6	81.2	72.6
	800	4810	14.4	1.9	5.8	0.2	0.2	43.1	73.0	81.1	72.8
	1600	4329	15.2	1.8	4.0	0.8	0.2	41.8	73.9	80.7	72.0
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Means are averages of 4 determinations; gypsum rate effect not significant (NS) at 5% level.

and Ca, Mg, and K contents of 786, 68, and 156 ppm, respectively. With these amounts of nutrients, especially Ca, it is not surprising that gypsum was ineffective in increasing the yield and quality of peanuts. Therefore, the excessive application of gypsum to peanuts is not necessary and can involve a waste of time and money.

Both foliar and soil Ca, Mg, K, Mn, Cu, and Zn obtained at harvest (Table 30) indicate no apparent variability as a result of gypsum rates. This reflects the initially high nutrient content of the soil. In the Early Bunch, Florigiant and Florunner peanuts, the levels of Ca in the plant tops ranges from 0.89 to 1.11%, 1.00 to 1.16%, and from 0.95 to 1.16%, respectively. In the three varieties for the three levels of gypsum, Mg ranged from 0.17 to 0.23% and K from 1.68 to 1.93%, respectively. Similar trends were observed for levels of Mn, Cu, and Zn.

The soil analyses data at the bottom of Table 30 indicates a trend of increasing Ca and decreasing Mg and K levels in the soil with rates of gypsum. Gypsum rates showed no effect on micronutrient levels. Reduction in both Mg andK with increasing rates of gypsum is in agreement with observations made by other researchers (28,79) and with the laboratory experiment studying the movement of gypsum and lime which was discussed earlier. Gypsum application induced the mobility of K and Mg from the soil and only Mg loss was reduced in the presence of lime. This loss of Mg and K need not cause concern with peanuts since gypsum is applied well after the plants have been established vegetatively.

Field Experiment III (1975)

In the spring of 1975, a third field experiment was conducted on Lakeland soil in the vicinity of the first field experiment. However,

Table 30. Soil and Plant Tissue Data of Three Peanut Cultivars as a Response to Gypsum in Arredondo fs in Field Experiment II.*

Variety	Gypsum	Ca	Mg	K	Mn	Cu	Zn	
				Plant Tops (0.1N HCl)				
	kg/ha		%			ppm		
Early Bunch	0	1.11	0.20	1.86	74.7	3.5	33.0	
	800	0.89	0.16	1.80	75.5	3.2	32.3	
	1600	1.10	0.22	1.83	92.0	4.0	42.3	
		NS	NS	NS	NS	NS	NS	
Florigiant	0	1.00	0.17	1.69	75.0	4.0	57.0	
	800	1.09	0.21	1.72	71.2	3.2	30.0	
	1600	1.16	0.23	1.89	75.2	3.5	28.3	
		NS	NS	NS	NS	NS	NS	
Florunner	0	1.16	0.21	1.93	90.7	3.0	31.5	
	800	0.99	0.21	1.72	70.5	3.5	49.3	
	1600	0.95	0.23	1.68	50.2	3.5	27.0	
		NS	NS	NS	NS	NS	NS	
				Soil ($\underline{N}$ NH$_4$OAc (pH 7)				
				ppm				pH
Early Bunch	0	257.3	36.3	79.3	2.2	0.1	11.5	5.9
	800	297.0	31.3	70.5	2.2	0.0	11.3	5.7
	1600	312.8	32.0	69.8	2.5	0.1	11.5	5.7
		NS	NS	NS	NS	NS	NS	NS
Florigiant	0	270.0	44.8	68.8	2.7	0.1	13.3	5.7
	800	267.0	30.5	64.5	2.5	0.1	10.3	5.7
	1600	333.8	30.3	66.8	2.5	0.1	11.0	5.5
		NS	NS	NS	NS	NS	NS	NS
Florunner	0	266.3	44.8	68.8	2.5	0.1	10.3	5.7
	800	297.8	29.3	65.3	2.5	0.1	11.8	5.5
	1600	293.3	26.8	60.8	2.5	0.1	16.0	5.7
		NS	NS	NS	NS	NS	NS	NS

*Means are averages of 8 determinations, gypsum rate effect not significant (NS) at 5% level.

the land had been cleared, planted to watermelons, and then was in grass for 3 years prior to the experiment. The inoculum and fertilizer treatments were similar to the first experiment except that the K sources were KCl, S-coated K_2SO_4, and K_2SO_4 (Table 4).

The analyses of variance (Table 31) shows no gross differences in the yield of pods, tops and quality of peanuts. However, significant difference among treatments were observed for the levels of Mg, K, Mn, Cu, and Zn in the plant tissue and for K and Mn in the soil after harvest. The yield, quality of peanuts soil, and plant tissue analyses are presented in Table 32 and borken down according to rates of inoculum, N, Mn, gypsum, and Kas S-coated K_2SO_4, soluble K_2SO_4 (SK) and KCl. Increases in both yield of pods and tops, were not significant, though trends were associated with increasing rates of inoculum, N, Mn and with all three sources of K. Mean yield of pods ranged from 4602 to 5642 kg/ha and tops from 5940 to 8940 kg/ha. However, no trend was observed in the yield of pods and tops with increasing rates of gypsum; there was a trend for extra large peanuts to be increased with rates of gypsum.

The above results are consistent with those in the previous field experiments. In this case also, the lack of response of yield and quality to fertilizer input, especially Ca, can be attributed to the fact that the soil had, initially, adequate nutrients ad indicated by the soil analyses prior to planting. The soil had a pH of 6.9, and 785, 155, and 131 ppm of Ca, Mg, P, and K, respectively. Brady and Colwell (18,19) and Foster (38) reported that response to Ca application was infrequent when extractable soil Ca levels were above 280 ppm. In this

Table 31. Analysis of Variance of Yield and Quality of Peanuts, Soil and Plant Tissue Data on Lakeland fs in Field Experiment III.

Response	Blocks	Treatments	Errors
Yield[†]			
Pods	240498	552014	509596
Tops	32258118**	4500273	3120980
% ELK	71.5507	69.3577	68.9598
% SMK	11756.4200**	24.9160	35.5036
Plant Analyses	0.8548**	0.1337	0.1197
Mg[‡]	1.8769	3.1909**	0.7724
K	0.05520	0.08324*	0.04341
Mn	8617	13281*	6315
Cu	67.3913	53.5415*	29.3004
Zn	122.6812**	44.3785*	22.0372
Soil (NH_4OAc)			
pH	4.3665**	0.1395	0.1280
Ca	325375**	17562	16013
Mg	2752.30**	167.80	143.10
K	588.1014**	140.1779*	69.0408
Soil (Double Acid)			
Ca	174450**	12179	12426
Mg	2817.34**	279.47	214.22
K	450.1848**	88.3577*	48.3590
Mn	64.4348*	35.9190**	16.3590
Cu	2.85217**	0.09055	0.08096
Zn	1.8522*	0.4602	0.4837
Fe	515.9239*	95.1700	58.3557
df	3	22	66

*Significant at the 5% level

**Significant at the 1% level

[†] ELK is extra large kernels; SMK is sound mature kernels.

[‡] Mean squares must be multiplied by 10^{-2}

Table 32. Yield of Pods, Tops, Soil and Plant Tissue Data of Florunner Peanuts Grown on Lakeland fs as a Response to Inoculum, Gypsum, N, K, and Mn.[†]

Rates	Yield		ELK	SMK	Plant Analyses			Plant Analyses		
	Pod	Top			Ca	Mg	K	Mn	Cu	Zn
	-----kg/ha----		--------%					---------ppm-------		
				Inoculum effect						
Yes	5229	7523	41.96	30.78	2.21	0.67	1.58	155	20	15
No	4735	7074	40.66	32.39	2.42	0.62	1.49	180	24	16
kg/ha				N effect						
0	4896	6721	42.02	31.30	2.47	0.50	1.64	179	24	17
100	5111	7384	39.77	32.10	2.39	0.66	1.55	174	22	17
200	4939	7792	42.14	31.35	2.09	0.79	1.42	151.	21	13
				Mn effect						
0	4788	6883	41.55	31.18	2.26	0.65	1.66	78.	23	17
10	5241	6820	40.64	21.23	2.20	0.64	1.40	269	23	17
20	4918	8194	41.75	32.33	2.48	0.66	1.40	269	23	17
				Gypsum effect						
0	5590	8953	35.50	30.00	2.31	0.67	1.53	153	22	14
100	4714	6838	44.45	29.90	2.39	0.64	1.54	148	19	17
200	4632	5940	44.95	34.40	2.17	0.67	1.57	155	25	15
400	4992	7466	40.35	32.04	2.38	0.62	1.51	205	22	16
				S-coated K_2SO_4 effect						
0	4658	6791	40.54	32.53	2.19	0.69	1.27	167	21	18
25	4994	6493	41.49	34.68	2.42	0.61	1.48	157	26	17
50	5385	8665	38.99	20.18	2.41	0.67	1.61	173	18	14
100	4892	7249	44.24	28.93	2.25	0.64	1.80	173	22	15
				K_2SO_4 effect						
0	4602	7209	36.92	33.41	2.23	0.66	1.30	213	21	18
25	4841	7313	41.61	30.81	2.33	0.67	1.64	188	20	16
50	5642	7794	45.86	26.81	2.49	0.64	1.49	163	23	16
100	4844	6880	40.86	35.31	2.20	0.63	1.72	107	23	13
				KCl effect						
0	4774	7031	40.26	34.56	2.29	0.70	1.33	222	21	18
25	4791	6914	45.70	31.46	2.48	0.74	1.48	168	31	15
50	5018	7830	41.35	30.85	2.42	0.63	1.65	181	21	15
100	5345	7422	37.95	29.46	2.07	0.53	1.69	100	16	14

[†] Means are averaged of 4 determinations.

experiment, even at harvest, the level of exchangeable soil Ca extracted with N NH_4OAc at pH 7 ranged from 200 to 400 ppm, and these were after leaching losses and plant uptake. Gypsum applications did not cause an increase in the level of Ca in the soil and in the plant tissue of the Florunner peanuts. However, increasing rates of N, Mn, and K were accompanied by an increase in the levels of the Mg, Mn, and K in the plant for the former and both plant and soil for the latter two nutrients. Regular foliage observations of plants that did and did not receive N application showed a much greener foliage for N fertilized plants than those without N.

At harvest the pH of the soil had dropped from 6.9, before planting, to 6.5 at harvest, as a result of leaching losses of bases and nitrification, especially Ca, Mg, and K. The low CEC of this soil coupled with high amounts of Ca added, renders this nutrient more susceptible to leaching losses as was observed in the above laboratory studies.

Potassium application from the three sources had no affect on yields of pods, tops and quality of peanuts and levels of K in both soil and foliage Table 33. This was not surprising considering the adequate level of K initially present in the soil (131 ppm). The added advantage of applying $CaSO_4 \cdot 2H_2O$, or K_2SO_4 and SCK as sources of S would be beneficial to soil of the less developed areas low in native sulfur.

Equations for significant regression relations of yield and plant and soil nutrient levels are presented in Table 34. Yield of pods increased with inoculum levels, tissue Ca decreased with rates of inoculum and applied N and is probably a dilution effect due to high yields of tops. Plant Mg, K and Mn varied linearly with rates of N and K sources, and Mn. The regression of pH was a quadratic effect with level of gypsum as was the Ca soil level extracted with NH_4OAc at pH 7, indicating a rise and then a decrease with rates of gypsum.

The experiment provides further evidence that unless the soil is extremely low in Ca or S, the application of gypsum, to provide Ca beyond that supplied by lime does not result in improvement of yield and quality of peanuts. In this experiment it is evident ath 2200 kg/ha lime provided adequate Ca in the soil for maximum yield and quality of the Florunner peanuts.

Field Experiment IV (1976)

The last experiment in the series of investigations was conducted on the same Lakeland soil in theproximity of the second and third field experiments of 1974 and 1975, respectively. The experiment, a split plot using four levels of $CaMg(CO_3)_2$ as main plots and seven treat-

Table [illegible]. Soil Analyses Data of Lakeland fs in Field Experiment III.

Level	Soil (Double Acid)							Soil (NH$_4$OAc) pH 7			pH
	Ca	Mg	K	Mn	Cu	Zn	Fe	Ca	Mg	K	
	ppm										
					Inoculum effect						
Yes	202.0	23.25	29.39	4.72	0.96	1.39	42	299	21	31	6.20
No	223.3	21.22	27.41	5.28	0.87	1.39	41	254	18	30	6.25
kg/ha					N effect						
0	203.9	25.73	29.29	7.17	0.80	1.17	42	280	21	30	6.20
100	177.8	17.80	26.77	3.86	1.05	1.26	47	248	14	30	6.10
200	256.3	23.18	29.15	3.98	0.89	1.74	36	300	22	33	6.29
					Mn effect						
0	193.0	16.57	28.30	0.04	0.95	1.37	46	241	14	30	6.13
10	196.6	21.04	28.20	7.98	0.91	1.43	43	303	21	32	6.29
20	248.4	29.10	28.70	7.08	0.89	1.39	36	285	21	31	6.30
					$CaSO_4 \cdot 2H_2O$ effect						
0	148.9	17.98	31.36	7.74	0.99	1.56	46	296	24	33	6.20
100	240.4	23.76	26.75	2.62	0.90	1.32	38	320	8	30	6.25
200	281.1	30.01	28.25	5.12	0.82	1.30	42	297	30	32	6.45
400	180.3	17.20	27.25	4.53	0.96	1.39	41	193	14	28	6.00
					S-coated K_2SO_4 effect						
0	275.4	30.47	21.42	5.78	0.92	0.90	39	298	24	24	6.23
25	170.4	17.49	22.81	4.16	1.15	2.42	38	279	19	26	6.20
50	197.9	16.49	27.81	3.15	0.97	1.15	42	251	13	30	6.23
100	207.1	24.49	41.56	6.91	0.62	1.10	47	277	21	43	6.20
					K_2SO_4 effect						
0	196.5	21.09	25.36	3.09	0.94	1.21	36	226	19	23	6.07
25	131.8	8.37	25.00	4.47	0.82	1.35	39	231	17	24	6.19
50	298.8	27.62	27.00	3.72	1.07	1.58	41	265	23	28	6.19
100	223.5	31.87	36.25	8.72	0.82	1.43	50	382	18	48	6.50
					KCl effect						
0	239.0	26.61	24.10	5.36	0.89	1.25	40	257	18	27	6.14
25	210.5	21.13	27.25	5.50	1.03	1.32	40	286	24	31	6.20
50	197.7	24.33	28.25	6.65	0.92	1.41	47	303	19	31	6.30
100	203.5	16.88	34.00	2.50	0.83	1.59	39	258	16	34	6.20

Table 34. Regression Equations for Yield and Plant Data of Florunner Peanuts and Soil Data of Lakeland fs in Field Experiment III.

Response	Equation for Dependent Variables*
Pods	$4530.47 + 241.91I$
Plant Ca	$2.2998 - 0.09861I - 0.1504N$
Plant Mg	$0.5746 + 0.1332N - 0.0277K$
Plant K	$1.0792 - 0.1149N - 0.1050C + 0.0762S + 0.0863K$
Plant Mn	$183.56 + 105.19M - 25.501C - 25.602K$
Plant Cu	$20.333 + 22.729K - 17.380K^2 + 2.818K^3$
Plant Zn	$23.250 - 9.7851M - 1.3523N + 4.5795M^2$
pH	$5.9834 + 0.3827G - 0.0996G^2$
$\underline{NH_4OAc}$	
Ca	$264.17 + 118.25G + 32.109S - 33.285G^2$
Mg	$28.250 - 37.940G + 35.222G^2 - 6.532G^3$
K	$12.384 - 2.249S + 3.920C + 1.856K + 2.055S^2$
Mg	$27.226 + 3.651S$
K	$14.936 + 0.6120C + 2.1047S + 1.8556K + 1.0904C^2$
Mn	$4.2924 + 3.7924M + 1.3765S$
Zn	$0.6312 + 3.429C - 2.560C^2 + 0.4253C^3$
Fe	$39.855 + 14.155N - 8.135N^2$

*Symbols for rates are I = Inoculum, $N = \frac{N}{100}$, $M = \frac{Mn}{100}$, $G = \frac{gypsum}{100}$, $C = \frac{C\text{-}K_2SO_4}{25}$, $S = \frac{K_2SO_4}{25}$ and $K = \frac{KCl}{25}$

ments of $CaSO_4 \cdot 2H_2O$ and $CaCl_2$ as subplots, was conducted to determine the best Ca source for peanut and whether lime alone would be adequate to meet the Ca requirement of the Florunner peanut.

The mean yields of pods and tops are presented in Table 35. Yield of pods was significantly affected by rates of $CaMg(CO_3)_2$. Rates of $CaCl_2$ and $CaSO_4 \cdot 2H_2O$ had no significant effect on the yield of pods and tops.

Dolomitic limestone [$CaMg(CO_3)_2$] increased yield of pods and top from 5641 to 6139 kg/ha and from 3977 to 4046 kg/ha; at the rates of 0 and 4000 kg/ha; respectively. Preliminary soil analyses of the experiment plots prior to planting indicated that the soil had a pH of 6.2 and 361, 22, 10, and 274 ppm of Ca, Mg, P, and K, respectively. The high levels of Ca and K and low amounts of Mg (19) are probably the reason for the observed response of yield of peanut pods and tops to $CaMg(CO_3)_2$ only.

The means of soil analysis data presented in Table 36 confirm the conclusion made above. Only $CaMg(CO_3)_2$ significantly affected pH and levels of Mg in the soil. The time of soil sampling significantly affected both pH and levels of Ca, lowering the former and raising the level of the latter, as a result of leaching and dissolution of $CaMg(CO_3)_2$ respectively. The failure of Ca levels to increase significantly with $CaMg(CO_3)_2$ rates is indicative of the initially high levels of Ca (274 ppm) in the soil. Amedee and Peech (8) and earlier results herein indicate that Ca losses increase with increasing rates of lime application and are proportional to the degree of Ca saturation. The low CEC of the Lakeland soil (2-4 me/100g) facilitates the leaching of any Ca in excess of that required to saturate the exchange capacity. This is probably the reason for the lack of significant increase in the levels of Ca with increasing rates of lime.

Table 35. Effects of $CaMg(CO_3)_2$, $CaSO_4 \cdot 2H_2O$ and $CaCl_2$ on Yield of Pods and Tops of Florunner Peanuts on Lakeland fs in Field Experiment IV.

Material	Rate	Yield†	
		Pods	Tops
	--------------kg/ha--------------		
$CaMg(CO_3)_2$	0	5641	3977
"	1000	5398	4133
"	2000	5679	3698
"	4000	6139	4046
Sig. effect		L*	NS
$CaCl_2$	0	5748	4083
"	200	5164	3753
"	400	5853	3732
"	800	5852	4131
Sig. effect		NS	NS
$CaSO_4 \cdot 2H_2O$	200	5896	4097
"	400	5552	3890
"	800	5937	4058
Sig. effect		NS	NS

†Rate effects were significant at the 5% (*) and were linear (L) and not significant (NS).

Table 36. Soil Ca, Mg, K and pH as a Response to Ca Sources and Rate on Lakeland fs in Field Experiment IV.

Material	Rate	Soil Data (N NH_4OAc pH 7)†			
		pH	Ca	Mg	K
$CaMg(CO_3)_2$	(kg/ha)		-------ppm--------		
	0	6.1	275	32	11
	1000	6.6	359	62	11
	2000	6.6	332	67	11
	4000	6.7	349	84	11
	Sig. effect	L*	NS	L**	NS
$CaCl_2$					
	0	6.6	317	67	11
	200	6.5	313	61	11
	400	6.3	329	55	11
	800	6.5	332	59	11
	Sig. effect	NS	NS	NS	NS
$CaSO_4 \cdot 2H_2O$					
	200	6.4	314	54	11
	400	6.5	345	70	12
	800	6.5	347	63	11
	Sig. effect	NS	NS	NS	NS
	Time(days)§				
	14	6.6	284c‡	63	14a
	30	6.4	331b	60	11c
	60	6.4	329b	60	7d
	140	-	369a	62	12b
	Sig. effect	NS		NS	

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† Effects were significant at the 5% (*) and 1% (**) levels and rate effects were linear (L) or not significant (NS).

‡ Mean separation within columns by Duncan's multiple range test, 5% level.

§ Days after planting.

Mean levels of Ca, Mg, K, Mn, Cu, and Zn in the plant tops are shown in Table 37. The levels of all six nutrients were significantly affected by time of sampling and only the Mn and Mg levels varied with time and were dependent on the levels of $CaMg(CO_3)_2$. Calcium and Cu levels increased while K and Zn decreased with time and therefore with plant growth. There is a trend for Ca, Mg, and Cu to accumulate with time in the foliage while Zn and K are reduced; which is probably due to dilution effects.

The significant interactions of time and $CaMg(CO_3)_2$ presented in Table 38 indicate that $CaMg(CO_3)_2$ had an effect on level of Mg only at 60 days. This is probably an indication of period of maximum Mg uptake or accumulation by the plant. Levels of Mg increased and those of Mn decreased with time. This is to be expected since the plant relied only on Mn present in the soil while it was continually supplied with Mg from the slow-dissolving lime.

The significant interaction of $CaMg(CO_3)_2$ and time for both pH and levels of Mg in the soil is presented in Table 39. After 30 and 140 days pH and levels of Mg, respectively, increased with rates of $CaMg(CO_3)_2$. The delayed affect of $CaMg(CO_3)_2$ is because of its extremely low solubility as was pointed out earlier in this manuscript (1,2,68).

The failure of gypsum and $CaCl_2$ and the response to $CaMg(CO_3)_2$ to increase yield of pods clearly indicates the peanut response was to Mg. The failure of $CaSO_4 2H_2O$ and $CaCl_2$ to affect yields as was the case in all the previous field experiments on soils with adequate levels of Ca, is because of the adequate levels of nutrients, including Ca, in the soil.

Table 37. Mean Values of Plant Analysis Data in Field Experiment as a Response to Rates of Lime and Fertilizer.*

Material	Rate	Plant Analyses Data					
		Ca	Mg	K	Mn	Cu	Zn
$CaMg(CO_3)_2$	(kg/ha)	%			ppm		
	0	1.43	0.42	1.68	26	11	19
	1000	1.40	0.44	1.66	22	11	16
	2000	1.33	0.48	1.67	23	10	19
	4000	1.41	0.53	1.68	22	11	17
	Sig. effect	NS	NS	NS	NS	NS	NS
$CaCl_2$	0	1.31	0.45	1.66	22b	10	18
	200	1.38	0.49	1.66	22b	10	17
	400	1.35	0.43	1.66	23b	10	17
	800	1.46	0.45	1.70	28a	11	18
$CaSO_4 \cdot 2H_2O$	200	1.38	0.47	1.65	23b	10	18
	400	1.41	0.49	1.68	23b	10	18
	800	1.37	0.48	1.69	23b	11	19
	Sig. effect	NS	NS	NS		NS	NS
	Time(Days)†						
	14	1.22c	0.33	1.96a	31	7c	20b
	30	1.20c	0.37	1.93a	27	10b	21a
	60	1.43b	0.56	1.52b	25	7c	16c
	140	1.67a	0.56	1.38c	13	17a	15d

*Mean separation within columns by Duncan's multiple range test, 5% level; rates were not significant (NS).

†Days after planting.

Table 38. Plant Mg and Mn of Florunner Peanuts as a Response to Time x Lime Interaction in Field Experiment IV.

Time days[†]	$CaMg(CO_3)_2$ kg/ha 0	1000	2000	4000
14	0.31b*	0.32b	0.34b	0.33c
30	0.37b	0.37b	0.37b	0.38c
60	0.41b	0.49a	0.56a	0.79a
140	0.54a	0.55a	0.59a	0.57b
	ppm Mn			
14	32a	29a	34a	30a
30	30ab	26b	26b	25b
60	30b	23c	25b	24b
140	15c	13d	22b	23b

*Mean separation within columns by Duncan's multiple range test, 5% level.

[†] Days after planting.

Table 39. Soil pH and Mg Level of Lakeland fs as a Response to Time x Lime Interaction in Field Experiment IV.

Time days†	$CaMg(CO_3)_2$ kg/ha			
	0	1000	2000	4000
	---pH---			
14	6.38a*	6.83a	6.76a	6.58a
30	5.94b	6.35b	6.51ab	6.69ab
60	5.97b	6.54ab	6.36b	6.69b
	---ppm Mg---			
14	36a	53a	73a	78b
30	32a	66a	65a	76b
60	32a	63a	60a	84ab
140	26a	54a	70a	95a

*Mean separation within columns by Duncan's Multiple range test, 5% level.

†Days after planting.

SUMMARY AND CONCLUSIONS

Laboratory, greenhouse and field experiments were conducted to study the effect of soil physico-chemical properties, lime, gypsum and fertilizer management practices on the yield and quality of peanuts on Florida and Malawi soils.

Mineralogical and selected chemical properties were determined on the Ap horizon of 10 soils of Malawi, eight Ultisol (Collected near Thulwe, Madisi, Euthini, Mbawa, Mjinge, Kasiya, Lisasadzi and Nsaru), one Inceptisol for Baka and one Entisol from Bapani. While kaolinite and quartz clay minerals were present in the clay fraction of all soils mica was present in all soils except in those from Nsaru and Bapani, and montmorillonite in the soil from Baka only. Kaolinite dominated the clay fraction of seven of the eight soil representing the Ultisol order and also in the soil from Bapani; and the content ranged from 47 to 81%. Montmorillonite (43%) and mica (33%) dominated the clay fractions of soil from Baka and Thulwe, respectively. Non-crystalline material, organic matter, and Fe_2O_3 in the colloidal fraction were low and varied from 8 to 18%, 4.8 to 16.4% and 0.3 to 0.7%, respectively. The pH measured in 1N KCl and ZPC values were lower than pH values measured in water indicating that the soils had a net of negative charges. Values of $BaCl_2$-TEA acidity, exchangeable acidity, CEC, exchangeable Ca, and the sum of exchangeable bases ranged from 2.41 to 12.10, 0.10 to 0.25, 2.60 to 21.18, 0.95 to 11.78 and 1.63 to 17.71 me/

100g, respectively. Levels of extractable Mn, Cu, Fe and Zn varied from 46 to 125, 0.3 to 1.5, 4 to 22 and 6 to 19 ppm, respectively. Clay and organic matter content were responsible for the observed differences in CEC and $BaCl_2$-TEA acidity; the Mn content was correlated with organic matter content. The Ca was consistently higher in soils that have a record of producing good peanut crops. The Ca levels in soils that produce poor peanut crops, Thulwe, Bapani, Euthini, Mbawa, Mjinge, and Lisasadzi were 1.58, 2.60, 1.14, 1.55, 0.95 and 1.38 me/100g, respectively. While the soils producing high peanut yields, Madisi, Baka, Kasiya, and Nsaru had Ca contents of 9.15, 11.78, 2.93, and 3.59 me/100g, respectively. Field and greenhouse experiment should be conducted on these soils to determine the source and levels of Ca to be used in the production of good quality peanuts.

In the laboratory experiment conducted to investigate the effect of 0, 3000, 5000 ppm $CaCO_3$ and 5000 ppm $CaMg(CO_3)_2$ on solubility of 1000 ppm $CaSO_4 \cdot 2H_2O$ and subsequent concentration of soil solution Ca, in Lakeland fine sand, Red Bay fine sand and Norfolk fine sandy loam, gypsum contributed a much higher soluble Ca concentration than either form of lime. The Asp for gypsum indicated that even at high lime rates the solubility product of gypsum was not reached hence gypsum would dissolve. The amount of Ca in the soil solution resulting from the dissolution of lime and gypsum will be influenced by the nature of the soil and the levels of exchangeable cations in the soil.

^{45}Ca-labeled gypsum was used in laboratory column studies to investigate the effect of different degrees of Ca saturation of the exchange complex on the rate of solution and movement of Ca supplied to the surface as gypsum. Because of the increased apparent CEC coupled with isotopic and cation exchange reactions, larger amount of ^{45}Ca was retained in the 0-10 cm segment of limed soil columns. In unlimed soil, cation outflow from the columns receiving gypsum application was increased. Further lime reduced the outflow of K and Mg from the soil columns and offset the acidifying effect of gypsum. The concentration of total Ca in the 10 cm of the soil column was increased with rates of lime and gypsum. This may be important in peanut nutrition in that lime not only could offset the acidifying effect of gypsum in acid soils but also increases the CEC of the soil.

In the greenhouse experiment, $Ca(OH)_2$ did not significantly increase yield of tops of Florunner peanuts but increased the pH of the soil. After the first increment of $Ca(OH)_2$ total yield of tops were reduced. Possibly because of soil pH level above 7.0. Higher rates of Mn also reduced total top yields.

In the four field experiments also involving inoculum, gypsum, clacitic and dolomitic limestone, N, Mn and K, only dolomite produced significant increases in peanut yield and this increase was attributed to a low supply of Mg. The inability of gypsum and any of the fertilizer materials to increase the yield and quality of peanuts in Lakeland and Arredondo fine sand soils was laregly because the soils initially had adequate levels of nutrients, more especially Ca. In none of the soils was the Ca level below 400 ppm or 2 me/100g. The high levels of Ca in these two soils are a result of prolonged use of lime which increased the effective CEC and percent base saturation of the soil.

Our experiments confirm that peanuts grown on soils with Ca levels about 400 ppm (2 me/100g) on soils dominated by 1:1 type clay minerals do not usually respond to $CaSO_4$ application. However if the total CEC is greater than 10 me/100g resulting in a percent base saturation (Ca) of less than 60 response may be expected. Also because of the higher bonding energy the quantity of Ca required in soils with 2:1 type clays will be greater. Of the Malawi soils examined, those known to be high or low producers of peanuts fit the 400 ppm Ca criteria except for the Bapani soil. This soil had a much higher CEC and contained significant quantities of 2:1 clay minerals and hence will require more Ca if it is to produce high peanut yields. Laboratory data on the other Malawi soils that produce low peanut yields indicate that the addition of lime to bring the Ca level up to 400 ppm or above should be sufficient to greatly increase peanut production.

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